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ELECTRONIC TRAVEL AIDS: NEW DIRECTIONS FOR RESEARCH

Working Group on Mobility Aids
for the Visually Impaired and Blind

Committee on Vision

National Research Council

AMERICAN FOUNDATION FOR THE BLIND
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FOREWORD

The Committee on Vision is a standing committee of the National Research Council's Commission on Behavioral and Social Sciences and Education. The committee provides analysis and advice on scientific issues and applied problems involving vision. It also attempts to stimulate the further development of visual science and to provide a forum in which basic and applied scientists, engineers, and clinicians can interact. Working groups of the committee study questions that may involve engineering and equipment, physiological and physical optics, neurophysiology, psychophysics, perception, environmental effects on vision, and treatment of visual disorders.

To perform its role effectively, the committee draws on experts from a wide range of scientific, engineering, and clinical disciplines. The members of the working group responsible for this report were chosen for their expertise in vision research and for their familiarity with past efforts by government and private agencies to harness advanced technology to serve blind and visually impaired persons. The report reflects their evaluation of the usefulness and durability of present-day mobility aids given the tasks confronting blind or visually impaired pedestrians. The report provides an account of the mobility task and of the perceptual, cognitive, and motor functions underlying the performance of that task. The report describes the people who might profit from using effective mobility aids and some of the techniques currently being used to judge the effectiveness of available aids. The report reviews information regarding the sensory systems available to blind and visually impaired pedestrians and the possibilities for the application of new technologies to the mobility task given those sensory processes.

The observations and recommendations arising from the efforts of the working group merit consideration by mobility specialists whether they are involved in the assessment and training of the blind and visually impaired, the design of the mobility aids to serve the needs of that population, or the support and conduct of basic research in this area.

Anthony J. Adams, Chair
Committee on Vision

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PREFACE

At the request of the National Institute of Handicapped Research and the National Science Foundation, the Committee on Vision established the Working Group on Mobility Aids for the Visually Impaired and Blind. The working group was asked to summarize current understanding of the basic dimensions of mobility, to comment on the status of devices that have been designed and built to assist the visually impaired people and to determine a research agenda that would strengthen the knowledge base underlying the design and use of mobility aids.

To accomplish these goals, the working group organized a workshop to review what is known about the design and use of mobility aids by visually impaired and blind people. Twenty-eight specialists in the fields of demography, performance assessment and training, psychology, geography, sociology, ergonomics, engineering, and physiology met for two days in Washington, D.C., in November 1985. Workshop participants were asked to consider the current state of mobility research and to suggest what further research would improve the design and use of mobility aids. Panels were formed and asked to address five major questions:

Panel 1: Who are the people who might benefit from travel aids? What dimensions might be used to classify them--along an age continuum, by kind of visual impairment, by degree of impairment? How well have people been able to use travel aids in the past? Why do some discontinue their use? In what ways are travel aids used differently in different environments?

Panel 2: Which travel aids have worked, which have not? Which training methods have worked, which have not? How can training and performance of visually impaired and blind people be assessed--by stride length, for example, or by focusing on whole-body movement? (The emphasis of this panel is the assessment of performance, not of electronic or other aids.)

Panel 3: What do blind or visually impaired people need (or might find useful) to know about the environment? Where in space is the information to be found--e.g., in the path ahead, at the surface on which they will walk? Are the processes involved conceptual? What is their relative dependence on perceptual information or on information retrieved from memory?

Panel 4: What are the capacities of the different senses to acquire information about space? How may acoustical and proprioceptive stimuli be used? How should information about space be displayed?

Panel 5: What kinds of aids are needed, given what we know about the kind of spatial information a person is likely to use? What are the limitations of existing devices? What are the new directions that might be taken in the development of new devices.

A background paper addressing the target questions was prepared for each panel and distributed well in advance of the meeting. Participants prepared a brief, informal response to their panel's background paper. Background papers and panelist responses were disseminated to all workshop participants in advance of the meeting to facilitate workshop proceedings. This report builds on those papers and comments as well as on discussions that took place at the workshop.

In addition to the 28 participants in the workshop, a number of people contributed in important ways to the success of the workshop and to this report of its recommendations. Wayne Shebilske, the committee's study director through June 1985, planned the workshop, and Pamela Ebert Flattau, the committee's study director after July 1985, provided important assistance in organizing the effort and in preparing the workshop report. Gora P. Lerma, the committee's administrative secretary, provided valuable secretarial and administrative assistance. Christine L. McShane, editor of the Commission on Behavioral and Social Sciences and Education, helped improve the style and clarity of the report. And finally, Estelle H. Miller of the National Academy Press lent her excellent production skills to the project in preparing the report for publication.

Emerson Foulke, Chair
Working Group on Mobility Aids for
the Visually Impaired and Blind

SUMMARY AND HIGHLIGHTS

In this report we identify the most promising directions for research on the mobility problems of visually impaired and blind people. We show that information is not generally available on the number of people who might benefit from electronic travel aids. Although we have made some guesses about the prevalence of visual impairment and blindness in the United States, we believe them to be underestimates of the true rates. Better information is needed about this population and should be collected with certain variables in mind: age, onset, degree of impairment, and certain social factors such as income level. Information is also not available on the use of electronic travel aids. More extensive follow-up studies are needed to determine the usefulness and success of particular devices.

Related to the use of electronic travel aids is the problem of the assessment of mobility performance in general. In this report we show that significant advances have been made in the development of objective measures of overt performance. These measures have not received widespread distribution, however, in part due to inadequate documentation of the techniques and the requirement for specialized measurement equipment to apply them. Accordingly, we believe that greater emphasis should be placed on the development and dissemination of promising assessment measures--objective and subjective, direct and indirect--and that emphasis should be given to these assessment methods in training programs for mobility specialists.

Mobility is undertaken with a purpose in mind, that of reaching a destination. We have attempted to outline the nature of the perceptual processes and the cognitive knowledge base available to the blind pedestrian. In the absence of a sufficient theory of mobility, however, the theoretical underpinnings of blind mobility depend on the research traditions in perception and cognition. Unfortunately, research with blind individuals has received far too little attention by experienced investigators, although there are some notable exceptions. Research is needed on how much information is required by the blind traveler, the use of natural cue correspondence, the role of information redundancy, orientation in space, and the nature of the perceptual-motor learning processes that underlie the use of mobility aids.

There is an urgent need to determine how--and to what extent--sensory substitution or enhancement techniques can best be used to

compensate for deficiencies in the acquisition of spatial motor behaviors in people with visual impairments. The visual system is capable of resolving information in both the immediate and remote environments, but this is not always true for auditory or somatosensory modalities. More emphasis is needed, therefore, on research exploring the possibility of coding spatial distance through a sonar system with some complex form of acoustical amplitude, and on the design and development of an artificial device to simulate tactile perception. With respect to the enhancement of low vision, common measurement metrics expressed in visual terms need to be developed to evaluate vision substitution systems.

The first generation of mobility aids (e.g., the Russell Path-sounder, the Laser Cane, the Mowat Sensor) was criticized on grounds that included cost-effectiveness and the masking of natural echo and location cues. In the late 1970s and early 1980s, developers came up with some new solutions to address these problems. Nonetheless, existing devices still have limitations. We believe that further improvements in electronic mobility aids will be limited less by technological considerations than by the determination and definition of the information needed by the traveler and the capacity of the nonvisual senses to process the information via a suitably encoded display. This report attempts to direct future research so that we will learn more about visually impaired or blind travelers--how many there are, the prevalence of various impairments, how to assess their performance, what information they need about space to move about safely and efficiently, and what displays are likely to meet their information needs. Compared with these issues, the development of appropriate technology is relatively straightforward.

Highlighted below are some of the most important points we make, cross-referenced to the appropriate recommendations in the report:

- Independent travel is an important goal sought by most visually impaired and blind people. While the long cane has significantly improved their mobility, many hope that advances in electronics technology will yield an electronic travel aid (ETA) that provides the same type of information about space as that which guides the travel of sighted pedestrians. To date, no ETA has been built that permits travel performance similar to that of sighted pedestrians or that enables independent and safe travel by visually impaired or blind pedestrians in unfamiliar surroundings. A better understanding of the factors underlying the mobility process is needed if effective ETAs are to be designed, developed, and used.
- Information is generally unavailable about the size, characteristics, and needs for mobility of the population to be served by electronic travel aids. Surveys are needed to provide better information about users of this technology and about the factors that contribute to the nonuse of ETAs. (See pp. 23-24, 76)
- Better and more consistent information should be collected on mobility performance. Objective measures are usually not used

outside the laboratories in which they were developed. Widespread use of improved measures of mobility would facilitate the comparison and/or replication of research on the problems of visually impaired and blind people; such information would also improve training strategies and enhance the use of ETAs. (See pp. 33, 74)

- It is generally accepted that, in order to engage in safe and efficient travel, pedestrians must have access to certain categories of information about the environment: the presence, location, and nature of obstacles; the texture, slope, and boundaries of the path or travel surface; and the spatial orientation. People vary widely--whether sighted, partially sighted, or blind--with respect to their selection and use of information about their surroundings when moving from one place to another. Advances in mobility research will depend on identification of the critical information used by the traveler. (See pp. 49-52, 75)
- Different methods of displaying information needed for mobility should be carefully designed to match the sensory system and should be tested by experimentation. It is possible to simulate information displays, manually or with simple technology, to test their effects on mobility performance. Yet simulation methods are often overlooked as an approach to the study of mobility performance. (See pp. 33-34, 50-51, 65, 75, 78-80)
- Further improvements in electronic travel aids will be limited less by technology than by knowledge of the information needed by the traveler and the capacity of the nonvisual senses to process that information in suitably coded displays. Research is needed on how to match auditory, tactual--and, when appropriate, visual--information displays to sensory processes so that information about the environment can be selected and used by the blind or visually impaired traveler. (See pp. 51, 62-64, 77-78)
- To implement the working group's recommendations, it will be necessary to enhance cross-disciplinary research on the mobility problems of blind and visually impaired people. Incentives must be provided at the national level to attract the most able researchers from a broad spectrum of fields to apply their skills to the problems of mobility outlined in this report.

Chapter 1

INTRODUCTION

Problems related to mobility and written communication account for most of the disability experienced by those who have little or no vision. Mobility problems are serious because of the instrumental character of mobility. Most human activities are carried on in particular places, and no matter how skillful a person may be in other respects, he or she will be excluded from participation in those activities by the inability to get to where they are carried on.

With the introduction of the long cane in the 1940s (described in Chapter 6) and of techniques for using it (Hoover, 1968), it became apparent that the mobility of blind pedestrians could be improved significantly with training. To provide this training, specialists of a new kind, called mobility specialists, soon appeared.

Although the improvement in mobility made possible by proper use of the long cane is undeniable, a long cane is, at least at first glance, a rather simple travel aid of limited capability. Since the 1960s, many have expected that by exploiting the possibilities offered by a burgeoning electronics technology, it should be possible to build an electronic travel aid (ETA) that could provide much of the critical information about space that accounts for the ease of mobility of sighted pedestrians and that is not available to blind pedestrians. However, as the years passed and attempt followed attempt, it became apparent that the potential offered by ETAs was not being fulfilled. Although some improvement in performance could often be attributed to their use, in most cases the improvement was modest (Shingledecker and Foulke, 1978; Brabyn, 1982). The mobility of a blind pedestrian using an ETA should, in the opinion of some, approach the mobility of a sighted pedestrian (Leonard, 1968). Though many would regard this criterion as unrealistic, they would at least insist that the improvement enabled by an effective ETA should be more than modest. The ETA should make a difference that is obvious and indisputably significant. A successful ETA should enable independent, efficient, effective, and safe travel in unfamiliar surroundings.

To date, no ETA has been built that can meet even the less demanding of the criteria just mentioned, and it is commonly recommended that an ETA be regarded as only an ancillary aid to supplement a primary aid: the long cane or the dog guide.

In recent years, although the power of electronics technology has continued to grow at a geometric rate, few have been tempted by the possibility of building a better ETA. The fact that a long cane, costing perhaps \$10, has proved to be more useful by far than an ETA costing as much as \$4,000 suggests that we do not yet know enough about the task of mobility and the human beings performing that task to specify the functions of an ETA. Before any further attempts are made to build ETAs, we must gain a much better understanding of the mobility problem than we currently have. We need to know what spatial information blind and visually impaired pedestrians need, whether preprocessing of the data acquired by ETAs will be required, how spatial information should be displayed, and to what sense or senses.

The chapters that follow constitute an effort to render an account of the mobility task and of the perceptual, cognitive, and motor functions of the blind and visually impaired pedestrians who perform that task. Our account is consistent with the data currently available and suggests the questions that must be answered in order to specify the functions of a successful travel aid. In these chapters it will often appear that more attention has been given to blind pedestrians and the task they perform than to pedestrians with useful remaining vision and to the task they perform. We are well aware of the important perceptual differences between blind and visually impaired pedestrians and the important differences between the tasks they perform. Many investigators believe, however, that an initial emphasis on the problems confronting blind pedestrians is the best approach to take in seeking a basic understanding of the mobility problem in general.

THE PROBLEM OF MOBILITY FOR BLIND AND VISUALLY IMPAIRED PEDESTRIANS

The Mobility Task

The task confronting blind pedestrians is the task of independently traveling from a starting place to a destination. This may appear, at first glance, to be a simple definition, but when the information and abilities needed for its performance are taken into account, the apparent simplicity vanishes.

Mobility is more than the ability to avoid obstacles while moving aimlessly through space. Mobility worthy of serious interest is that undertaken with a purpose in mind, that of reaching a destination, and, if pedestrians are to reach destinations, they must know not only what those destinations are, but also where they are. They must be oriented, and they must be able to maintain the currency of orientation as they move through space.

Performance of the mobility task demands what Poulton (1957) has called an open skill. Because the task is performed in an environment that is changing and only partially predictable, its performance must be guided by feedback--both internal, somesthetic feedback and external feedback in the form of information acquired from the space in which the task is performed. Relevant information must be differentiated

from a background of irrelevant, often masking stimulation. The requirements of the task are not adequately specified by information acquired from the space in which the task is performed while the task is in progress, and the blind pedestrian must supplement this information with information retrieved from memory. Finally, the observation of task performance is often difficult because the behavior to be observed is embedded in highly integrated sequences of behavior, and because critical task components must often be inferred from their behavioral consequences.

Abilities and Skills

To say that a person exhibits an ability is to say that he or she is able, by some action or combination of actions, to produce an intended effect. An effect may be overt and observable, as when a person's actions produce some environmental change, or not directly observable and established by inference from its behavioral consequences, as when information acquired by perception is stored in memory. The performance of a task usually requires the production of more than one effect, and its performance usually demands the proper timing and sequencing of effects.

To understand the performance of a task, more than one level of analysis may be required. At the first, most immediate level, an attempt is made to identify the overt and observable effects on which accomplishment of the task depends. However, explanations at this level of analysis are often inadequate, and it becomes necessary to move to a second level of analysis, at which many of the actions and the effects of actions that help to account for the performance of a task must be established by inference. Explanations of task performance at this level are usually in terms of perceptual, cognitive, and motor functions.

A skill is a developed proficiency or mastery, an ability that has been improved by practice or training or both. Many skills, when examined, are found to be composite skills; that is, they are the integrated expressions of component skills that are either directly observable or inferred from their behavioral consequences, or both. The skill required to perform the task of moving from a starting place to a destination is such a composite skill.

In his analysis of the mobility task, Brambring (1985) divides the skills on which performance depends into three groups: prerequisite skills, necessary skills, and desirable skills. Prerequisite skills are skills that are not unique to the task but that must be developed before the task can be attempted. For example, a pedestrian must be able to walk or at least have some means of locomotion before attempting the mobility task.

Necessary skills are those skills without which the task cannot be performed. Obstacle avoidance is one example, and the actions it implicates are observable. The use of landmarks to maintain orientation is another example, but the cognitive functions implicated by this skill are not directly observable and must be inferred from their behavioral consequences.

Desirable skills are skills that, although they enhance performance of the mobility task, are not necessary for its performance. The skill required to walk at a speed that does not cause interference with other pedestrians who are performing the same task, at the same time, and in the same setting is an example of a desirable skill. The elimination of interference is not a condition on which task performance depends. If the blind pedestrian performing the task walks at a much slower speed, he or she may interfere with other pedestrians, and the cost in time to the blind pedestrian may be considerable, but the task can still be performed.

The task confronting blind pedestrians, as we have suggested, is the task of independently traveling from a starting place to a destination. Successful mobility involves much more, however, than just the act of reaching a destination. The fact that an obstacle has not been hit does not always warrant the inference that a pedestrian has avoided it by the exercise of perceptual, cognitive, and motor skills--he or she may simply have been lucky. Measures are needed to determine the success with which the blind pedestrian has performed the mobility task. These measures involve the development of performance criteria.

Establishing Performance Criteria

A performance criterion is a standard against which a performance to be evaluated is compared. If the performance to be evaluated is equal to or greater than the standard, the criterion has been met. The criterion may be a standard of excellence: Rudolf Serkin's performance of a Beethoven sonata would serve, for instance, as a standard of excellence against which to compare the performances of aspiring pianists. More commonly, a criterion denotes a level of performance that marks the boundary between adequate and inadequate performance.

A performance variable may be found that is believed to be an adequate indicator of the composite performance of the whole task, because the value it assumes is jointly determined by a number of component variables, and a criterion could be established for this indicator variable. Motor ability is one determinant of walking speed; an elderly person with weak musculature or arthritis, for example, will walk more slowly than a person who does not have these limitations. Walking speed is also determined by the perceptual anticipation of which a pedestrian is capable. If little perceptual anticipation is possible, the time required to plan the actions that will be needed to cope with upcoming situations must be gained by walking more slowly. A pedestrian with some perceptual anticipation afforded by some residual vision, or by a travel aid that provides information about the characteristics of the path some distance ahead, will have more time for planning actions and will therefore be able to walk faster. The amount of perceptual anticipation needed is also a function of the environmental conditions (i.e., complexity, irregularity, congestion, etc.). These and other such variables act in combination to determine walking speed, and if their values are appropriate, walking speed should be

adequate. A walking speed that is at or above the criterion speed provides some assurance, therefore, that the component skills required for the mobility task are adequate.

Component Skill Criteria

Indicators of composite performance provide no enlightenment concerning the particular combination of component variables that are responsible for the observed value of the indicator variable. There could be many such combinations, including some in which there are values indicating unacceptably low levels of some of the component skills. Leonard (1972) and Armstrong (1975) have proposed the establishment of criteria for the component skills on which performance of the mobility task depends. Obstacle avoidance, measured by counting unintended bodily contacts with objects in the surrounding space, and skill in navigating, measured by counting unintended departures from the path, are examples. The pedestrian whose performance of each of these skills reaches criterion also meets the composite criterion of safety, which applies to the mobility task as a whole. By the same token, the whole-task criterion of efficiency is satisfied by reaching the criterion for economy of time on task, as indicated by the time spent walking divided by total time en route, continuousness of progress or the distance walked toward the destination divided by the total distance walked, and the skill that is demonstrated by choosing the most direct route.

Even if ways have been found to measure all the component skills that contribute to performance of the mobility task, there remains the problem of how to derive from these measures an indication of the skill with which the whole task has been performed. Is composite skill indicated by the number of component skills performed at or above criterion, or by the contour of a profile of the measured values of component skill variables, or by weighing and combining the measured values of component skill variables in some way to produce a single indicator?

GUIDE TO THE REPORT

The chapters that follow describe the research that has been done, that is now in progress, and that must be undertaken in order to resolve many of these issues. The report specifies the information that will be needed to improve the design, development, and use of mobility aids. Following this introduction, Chapter 2 presents a profile of the target population and what information is available concerning the factors that contribute to the use or rejection of available travel aids. Chapter 3 addresses the difficult problem of assessing mobility performance and points to important new directions for developing measures in that area. Chapter 4 outlines the dimensions of mobility from perceptual, conceptual, and environmental perspectives. Chapter 5 reviews the physiological mechanisms underlying sensory enhancement and substitution

and considers the success of environmental sensors in meeting the needs of the visually impaired or blind traveler. Chapter 6 provides a description of the technology of information acquisition and display, highlights the limitations of existing technology, and recommends new directions for the design and development of electronic travel aids.

Chapter 2

THE DEMOGRAPHY OF BLIND AND VISUALLY IMPAIRED PEDESTRIANS

To meet the needs of visually impaired and blind people by building more effective mobility aids, it is important to get a better sense of the size and characteristics of the population to be served. Such information would be helpful not only for service delivery but also for the design and development of travel aids that more closely match the population needs and the patterns of use and nonuse among these individuals. This chapter reviews the definitions of visual impairment that are used for purposes of demographic analysis, reports findings from available statistics about the number and characteristics of the visually impaired population, and describes what is known about the patterns of use of travel aids today. The chapter concludes with recommendations for further work to improve our understanding of demographic characteristics relevant to the mobility needs of visually impaired and blind people.

SOME DEFINITIONS

In disability-related research and policy generally, some common definitions have been developed to describe all types of impairment. Although terminology may vary, agreement has emerged around a set of four concepts: pathology, impairment, disability, and handicap.¹

Briefly defined, pathology refers to a medically determined disease or disorder (including trauma, structural abnormality, etc.). Impairment refers to lasting consequences of pathology, affecting parts of the organism. Disability refers to limitations in carrying out tasks. At this level of analysis, the individual and inevitably such factors as motivation, training, and the resources (aids) available to help accomplish tasks are involved.

Handicap refers to limitations in performing social roles (socially structured sets of tasks). At this level, the characteristics of the

¹The studies that are the basis for this consensus include reports by the Social Security Administration, the World Health Organization, and the Office of Technology Assessment.

social environment, including socioeconomic resources, discrimination, and characteristics of the individual, are involved.

Whatever criteria are used to identify the population of visually impaired people in the United States, there are several ways to classify subgroups of that population in relation to their probable use or nonuse of mobility aids. The size and demographic characteristics of that population will presumably be different depending on which of the concepts is under study. There are also likely to be varying degrees of overlap among the groups defined in this way. Our focus in this report is on disability--i.e., the limitations of visually impaired people in carrying out the tasks of mobility. Demographic information about the visually impaired population in terms of pathology, impairment, and handicap is important mainly in terms of its relevance to mobility tasks.

Unfortunately, available statistics on the blind population are grossly inadequate. We are forced to make estimates that may be out of date or unrepresentative as well as not focused on the most pertinent determinants of disability. Psychosocial factors, such as access to support groups and rehabilitation services and income level, are important predictors of disability for which there are few available data.

The measure that is most readily available to draw a demographic profile, legal blindness, suffers in that it does not address many relevant factors that contribute to disability. Legal blindness is defined in terms of two aspects of visual impairment, acuity and field size (i.e., acuity of 20/200 or worse in the better eye with correction or a visual field of 20 degrees diameter or less). It does not take into account other visual factors, such as sensitivity to glare or light and dark adaptation, that also affect mobility and other visual tasks. Specific types or degrees of impairment reveal very little about disability for any individual person. Very often two people with identical impairments have markedly different disabilities. The field of nonmedical rehabilitation, in fact, aims to reduce the disabilities associated with given impairment and justify the need for individual rehabilitation plans. Although the estimates have many limitations, we use statistics on the prevalence, incidence, and demographic characteristics of legal blindness in the United States in the next section to describe the legally blind population.

DEMOGRAPHIC CHARACTERISTICS

It is possible to estimate the number of legally blind people--the prevalence of blindness--in the United States today using the Bureau of the Census projections of the population and the estimated prevalence rates. The prevalence rates published in Vision Problems in the United States (National Society to Prevent Blindness, 1980) and the projected population for the years 1985 and 2000 are presented in Table 1. These prevalence rates are generally believed to be underestimates of the true rates and unrepresentative, since they are based on limited sampling plans or registries that are out of date. In addition, survey defini-

TABLE 1 Estimated Prevalence of Legal Blindness in the United States, 1985 and 2000

Age	Number of Legally Blind Persons				Total U.S. Population		Legal Blindness Prevalence Rate (per 1,000)
	1985		2000		(in thousands)		
	Number	Percent	Number	Percent	1985	2000	
0-4	7,750	1	7,403	1	18,453	17,626	0.420
5-19	31,924	6	35,248	5	51,824	57,220	0.616
20-44	100,513	17	102,849	14	95,093	97,303	1.057
45-64	110,023	19	150,023	20	44,652	60,886	2.464
65-74	107,333	19	112,567	15	16,855	17,677	6.368
75-84	137,023	24	186,359	25	9,057	12,318	15.129
85 +	80,996	14	147,938	20	2,697	4,926	30.032
Total	575,562	100	742,237	100	238,631	267,956	

NOTE: Prevalence refers to the total number of cases in the general population. Legal blindness is an administrative definition that includes persons with 20/200 acuity or worse in the better eye with correction or a visual field of 20 degrees diameter or less.

SOURCE: National Society to Prevent Blindness (1980).

tions may exclude some people with low vision (i.e., having a visual impairment that affects mobility but who are not legally blind), thus contributing to an underestimation of the population of interest. These sources remain, however, the best estimates available today.

For large groups of people who share the same category of impairment, it is possible to draw some inferences about disability and the presence of mobility problems in a probabilistic sense, even though the prediction will not be valid for all individuals in the group. Therefore it is important to examine the characteristics of the legally blind population that might be useful in making inferences about disability: age, age at onset, degree of impairment, other impairments, and social factors.

Age

The number of cases of blindness for different age categories can be calculated by multiplying the prevalence rate times the population count for each age category. That calculation or estimate is shown for the years 1985 and 2000 in Table 1.

The prevalence of blindness in the population is greatest in the older age categories. This is in part due to the simple accumulation of incidence with age, but this alone cannot explain the large increase in prevalence in the oldest age categories. Figure 1 shows the 1985 estimates plotted as percentages by age groups. For example, the age group 20-44 is almost 40 percent of the population, yet it constitutes only 17.5 percent of the blind population. The age group 75-84 constitutes approximately 4 percent of the population in the United States and 24 percent of the blind population.

More than half the blind people in the United States today are over the age of 64. This can be seen graphically by plotting the ratio of the percentage of blind people in each age group to the percentage of people in the U.S. population in the same age group (Figure 2). People under the age of 45 are underrepresented in the blind population, whereas people in the 85 and older group are overrepresented in the blind population by better than a factor of 12.

The U.S. population is aging. The median age increases each year--or, put differently, the relative proportion of people in the older age groups is on the rise. By the year 2000, it is predicted that the U.S. population will increase by 12 percent, yet the blind population will increase by 29 percent. This prediction assumes constant rates of prevalence; thus, all the disproportionate increase is due to the aging phenomenon in the U.S. population. The assumption of constant rates could lead to inaccurate estimates if, for example, there occur improvements in eye care and the prevention and treatment of eye problems or, conversely, greater incidence of impairment.

Although over half of all blind people are over the age of 64, there remains a large and significant group of people who are blind before the age of 20, approximately 7 percent, and an even larger group who are blind before the age of 45, approximately 24 percent. For

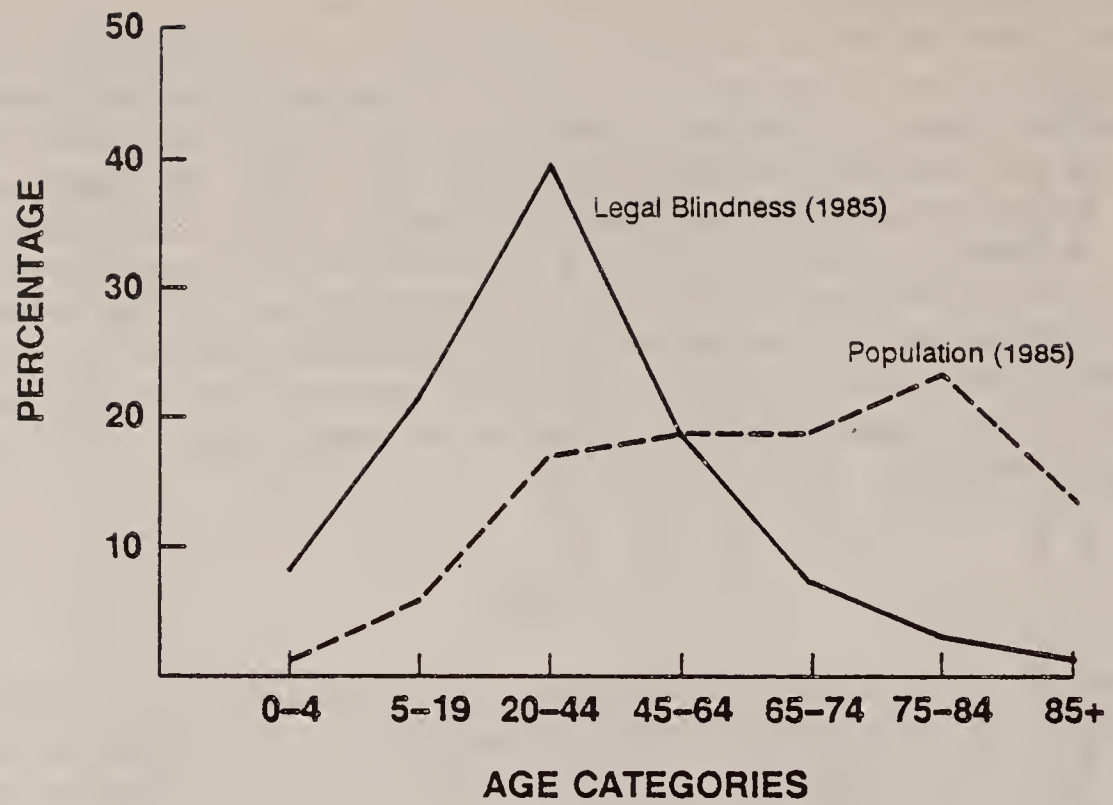


FIGURE 1 Distribution of legal blindness in the general population by age group, 1985.

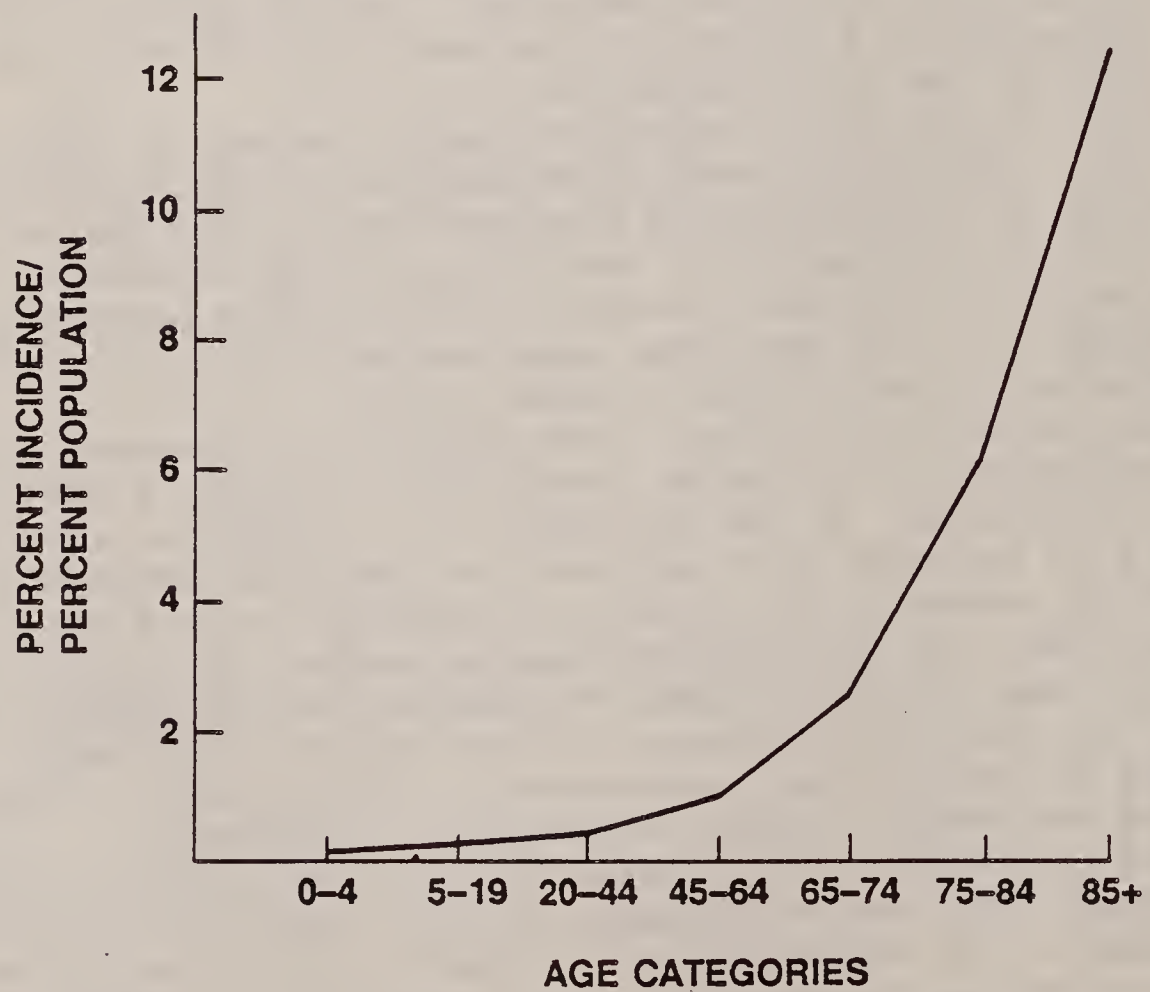


FIGURE 2 Ratio of percentage of blind people to the percentage of people in U.S. population by age group, 1985.

these individuals, blindness is a condition of life during the period in which they are likely to be most economically productive.

Onset of Visual Problems

The age at which impairment occurs is an important factor. The usual classifications distinguish between those who are blind from birth or at less than five years of age--congenital blindness--and those who have lost sight at older ages--adventitious blindness. The key to this distinction is the role that early visual experience plays in establishing spatial concepts and visual memories, which later aid functioning when visual impairments reduce or eliminate the ability to see.

Table 2 presents the incidence of legal blindness--i.e., new cases of legal blindness by age and etiology published in Vision Problems in the United States as estimated for the year 1978. The rate of incidence in the population is roughly stable at 0.01 percent until the age of 45; it then increases for each age group, achieving its highest rate, 0.27 percent, for the 85 and older age group. The distribution of etiologies within age groups changes with age. For example, the most frequent causes of blindness under the age of 20 are infectious diseases, injuries, and prenatal influences. After the age of 44 the major causes are chronic diseases such as diabetes and macular degeneration.

Visual loss has several dimensions: the age at onset, the end point or eventual level of loss, and the rate of progress to reach the end point. Each of these dimensions may affect a person's mobility rehabilitation program.

Many authors have proposed phases through which an individual progresses from the onset of a disability. There is general agreement that some internal or psychological adjustments should occur prior to entering a mobility program for the disabled person to obtain maximum benefits.

Rehabilitation professionals have observed that individuals with slowly progressing loss of vision, such as retinitis pigmentosa (RP), tend to have a difficult time accepting mobility aids because of the stigma imposed by the aid and the lack of a specific timetable for when their vision will decrease. There often seems to be a hope that either the condition will not progress or that a cure will be found. Entering into a rehabilitation program and using a mobility aid seem to conflict with this hope and often severely affect the person's acceptance of mobility instruction. This type of individual can be contrasted to those who have a fixed loss with remaining vision (macular degeneration), who can be told that the condition will not progress to total blindness. Once the condition has stabilized, mobility instruction and the use of mobility aids are generally quite successful.

A characteristic of some RP patients is a slow adaptation to changes in light level. A transient problem of this sort may call for special devices to aid mobility during this transitory state.

TABLE 2 New Cases of Legal Blindness (Incidence) According to Etiology in the United States, 1978 (numbers in thousands)

	0-5	5-19	20-44	45-64	65-74	75-84	85+	Total
Infectious diseases	200	100	200	250	50	50	--	850
Injuries/ poisonings	200	350	500	400	100	50	50	1,650
Neoplasms	100	150	100	100	--	--	--	450
General diseases	50	100	1,050	4,700	4,300	6,700	3,900	20,800
Prenatal influence	800	2,250	1,500	1,150	300	200	--	6,200
Unknown or unspecified	150	650	1,750	3,600	2,550	3,000	1,150	15,850
Multiple etiologies	--	50	100	650	850	1,350	800	3,800
Total	1,500	3,650	5,200	10,850	8,150	11,350	5,900	46,600
As Percentage of Population:	.01	.01	.01	.02	.05	.16	.27	.02

SOURCE: National Society to Prevent Blindness (1980).

Degree of Visual Impairment

The legally blind population can be partitioned into those people who are "totally blind," in the sense that they have no sensitivity to light, and those with some sensitivity to light. It is obvious that the lower boundary of useful vision may be defined variously for various tasks and for different situations such as twilight or darkness. It is less obvious, but also true, that there is room for debate about the upper boundary of total blindness as well. For example, the category of "total blindness" is sometimes grouped with vision measured as "light perception only" to form the category of "no useful vision," but it is disputable whether light perception does provide useful information. Although there have been some efforts to partition this category further (Colenbrander and Spivey, 1976), there is a need to determine whether the proposed categories are functionally related to differences in accomplishing mobility tasks.² It is highly probable that different levels of disability affect the choice of mobility aids or the way in which they are used. For example, two broad categories of visual loss, reduced acuity and reduced visual field, present very different functional difficulties. Therefore, it is reasonable to expect that the possible use of mobility aids will vary depending on the type and severity of visual disability.

Table 3 shows the prevalence (total number of cases in the population) and incidence (number of new cases added each year) of legal blindness by degree of impairment in terms of number of cases and percentages estimated for the year 1978 based on the data reported in Vision Problems in the United States. The rate of both prevalence and incidence increase for all impairment categories with age. Roughly 20 percent of the legally blind could be categorized as having "no useful vision" (by adding together the categories of "total blindness" and

²Levels of blindness and visual impairment have been proposed for planning individual rehabilitation programs, travel capability, legal status, tax exemption, supplemental social security awards, and the like:

- I. Blindness:
 - 1. No light perception (total blindness)
 - 2. Light perception and crude form recognition
 - 3. Gross pattern recognition (light-assisted orientation)
- II. Low Vision:
 - 1. Best vision in better eye with conventional glasses or contact lenses to approximately 20/200 or 20/200 with gross field defects.
 - 2. Approximately 20/100 - 20/70 with or without field defects.
- III. Partial Vision:
 - 1. Approximately 20/60 or better: uses approach magnification and simple magnifier.

TABLE 3 Prevalence and Incidence of Legal Blindness by Level of Impairment in the United States, 1978

	Prevalence		Incidence	
	Number	Percent	Number	Percent
Totally blind	52,300	11	3,100	7
Light perception	57,200	11	4,200	9
Light projection	5,600	1	450	1
Less than 5/200	81,450	16	7,200	15
5/200 to 10/200	49,200	10	5,800	12
10/200 to 20/200	78,950	16	7,200	15
20/200	111,200	23	1,250	27
Restricted field	35,450	8	4,050	9
Unknown	26,650	6	2,100	5

SOURCE: National Society to Prevent Blindness (1980).

"light perception"), and 15 percent of new cases fall into this group. Most experts believe that the 20/200 category is overstated because many physicians do not attempt to determine the full extent of visual impairment once they have determined that an individual is legally blind (e.g., 20/200). Thus many cases in this category may actually be more or less severely impaired (American Medical Association, 1984).

Additional Impairments

A key factor in mobility problems is the presence or absence of other impairments. More than 50 percent of individuals with visual impairments also have one or more other impairments (Kirchner, 1985), either due to the same pathology (as in diabetes or in Usher's syndrome, in which deafness occurs) or with an independent etiology. The types and significance of such impairments range widely: mental retardation, affecting the ability to learn how to use an aid; emotional illness, which may affect the motivation to use an aid; orthopedic impairments, which limit ambulation directly; hearing impairments, which limit the use of some types of aids; and other health conditions, such as heart disease, which can result in weakness or pain. All these conditions

affect the type of information that the aid must provide and the type of service it might provide--for example, assistance for a visually impaired individual who uses a wheelchair.

The psychosocial characteristics of the individual that we have been discussing (e.g., income, access to services, impact of type of onset, etc.) provide relevant information for dealing with the disabling effects of vision loss on mobility that cannot be obtained from knowledge of the medical diagnosis alone. In fact, information on diagnosis is often used as an indirect (and weak) indicator of one or more of the above variables. Obviously, for purposes of the medical treatment of the pathology or for programs directed at prevention, the information on causes is more directly relevant. Knowledge of diagnosis might also be sought as an indicator of mortality rates. This information may raise difficult ethical issues with regard to public policy requiring the allocation of resources (e.g., for expensive mobility aids). In general, with the exception of diabetes, we do not have reason to expect high age-specific mortality rates due to the major causes of blindness in the United States.

Social Factors

Social factors affecting the need for, access to, and acceptability of mobility aids must also be considered. These factors are shared with the nonimpaired population. Some of them are relevant epidemiologically, i.e., related to the rates of underlying impairment. Some have independent effects on the rates of disability--that is, two people with the same impairment may have different degrees of disability depending on their social status. The latter effects occur because social groups have differential access to resources, and/or social norms make certain tasks more important; cultural influences may also make certain types of mobility aids unacceptable.

Several national studies, which differ in the ways they identify the population with visual loss (and therefore use different estimated prevalence rates) nevertheless lead to fairly consistent generalizations about which social factors are important and in what connections. Specifically, age has been consistently found to be the strongest correlate of rates of visual impairment--prevalence rates increasing with age. Age is also one of the main bases for defining social roles and therefore the scope and nature of mobility tasks. Age may also operate through social psychological means to indicate sources of resistance to the use of certain aids.

A second major social factor is income. Income has been found to be inversely related to prevalence of severe visual impairment, either because vision loss has led to loss of employment or because poverty has led to poor health conditions or poor access to health care. Among persons with severe visual impairment, those with low income are more likely to incur greater disabilities and greater handicap. This correlation may result from having fewer of the resources needed to accomplish tasks and receiving generally less social approval to maintain their roles as fully functioning employees or citizens.

Economic factors not only affect the individual, but also involve aggregate costs to society as a whole. A 1976 report on the social and economic costs of visual disability (Cahill and Woolsey, 1976) estimates that the loss in tax revenue and the costs of rehabilitation services, supplemental security income, eye care, etc., is over \$350 million (in 1976 dollars) per year. In addition, there is an estimated loss of income of over \$1.4 billion and direct medical costs, which probably cannot be reduced, of approximately \$3.6 billion per year (in 1976 dollars). In 1984 there were over 250,000 tax exemptions on federal income tax returns claimed for blindness.

APPROACHES TO AIDING MOBILITY

There are two major elements of the mobility problem that result from blindness. First, the blind traveler with no pattern vision must avoid obstacles and detect drop-offs. The second problem, which is less obvious and equally serious, is navigation. Sighted travelers have many landmarks, most of which are known through vision, to guide their way. These landmarks not only identify the location but are used in the memorial representation or cognitive map of the area. Deprived of vision, the blind person must use other types of landmarks and information to orient and navigate.

A variety of aids have been developed to help the blind traveler. These include long canes, dog guides, and electronic travel aids. A variety of ETAs has been developed, including sound echo ranging devices, reflected light ranging devices, a computer vision system that speaks messages to the blind traveler, and a dog guide robot.

ETAs can be roughly classified using a two-way classification scheme, illustrated in Figure 3. One dimension of the classification scheme derives from two philosophical approaches to the problem: sensory substitution and sensory supplementation. Sensory substitution attempts to use one of the blind person's remaining sensory systems as a substitute for vision. In this approach, the function of an ETA is to transduce and transform visual information into information that can be perceived by another sense. Both the tactual and auditory sensory modalities have been used as substitutes for vision. Critics of this approach point out that converting visual information to auditory information could overload the capacity of the auditory system and that the ETA's auditory signal often competes with naturally occurring and useful auditory information.

Sensory supplementation starts with the observation that many blind people achieve a high degree of mobility without electronic aids. The function of an ETA therefore is to provide additional information that is critical and not available otherwise. A device that could detect an object blocking a path and signal its presence supplements the information already available to the blind traveler. The problem dealt with by this approach is to discover what information about the environment is necessary for mobility and, of equal importance, when it is needed. Critics of this approach point out that the critical information is often embedded in a complex array of sensory information. Moreover,

	Transduce and Translate	Transduce, Process, and Translate
Sensory Substitution	Sonicguide Seeing with skin	
Supplementation	Mowat Sensor Laser Cane Pathsounder Nottingham Obstacle Detector	Guide Dog Robot Computer Vision

FIGURE 3 Two-way classification scheme of electronic travel aids.

the critical information may be relational and dynamic in its nature. Human sensory systems have the ability to analyze and interpret complex information flows, and this ability is lost with substitution systems.

The second dimension of the classification scheme divides ETAs into two categories: those that transduce and transform environmental information and those that transduce, process, and then transform environmental information (see Figure 3).

The boundaries of the classification scheme are not sharp; some of the devices categorized actually straddle the boundaries or have aspects that fit into more than one category. This is especially true of the signal processing that goes on in the device, since few if any devices simply transduce environmental information.

Of all the devices listed, only the Guide Dog Robot attempts to completely solve the navigation problem: it contains a complete internal navigation system. All the other devices assume that the cognitive capabilities of the blind person will suffice if the appropriate information is provided through sensory substitution or by information supplementation.

PATTERNS OF USE AND NONUSE

It is significant that none of these devices seems to be widely used or very popular. The initial impetus of ETAs came from engineers and researchers. The primary evaluation and testing concentrated on

the mechanics of the device and the testing of the unique application of some instrumentation (e.g., lasers). These devices and the promise of new technologies were initially viewed as viable alternatives to the long cane or dog guide. After greater interaction with mobility specialists and other professionals working in the area of blindness, ETAs were suggested as a supplement to the primary mobility aid (i.e., the long cane or dog guide).

It has only been during the last 15 years that follow-up evaluations have been done to determine the usefulness and success of ETAs. There have been very few studies of this nature published, and they represent a great deal of variation in methodology, sample size, and number of data gathered. Sample sizes range from 5 to 74 individuals. The methods used for gathering data include mail questionnaires, phone questionnaires, direct observation, and personal interview. The length of time the visually impaired person had the device ranged from a few months to about 11 years. The ETAs used by the subjects included the Sonicguide, the Mowat Sensor, the Laser Cane, and the Russell Path-sounder. (See Chapter 6 for a description of these aids.)

Airasian (1973) mailed questionnaires to 94 individuals trained to use the Sonicguide (74 were returned). Many dimensions of attitudes about training, design difficulties and inconveniences, and adequacy of the device, range, and signals were gathered from the questionnaire. One basic question on the questionnaire was whether the person still had the Sonicguide. More than 10 percent no longer had the device, 11 percent still had it but had not decided about returning it, and 79 percent planned to keep the device.

Darling et al. (1977) evaluated the 26 blind veterans receiving ETA training at the Western Blind Rehabilitation Center in Palo Alto, Calif. The procedure involved a phone survey and direct observation in the veterans' home area. Of the 26 veterans who had been trained, 3 had moved and 5 did not use the device. Of the remaining 18 subjects, 12 had the Sonicguide and 6 had the Laser Cane. The time since training ranged from 1 to 5 years.

Of the 12 veterans having the Sonicguide, 5 were using it and 7 did not use it. Of the 6 people who had taken the laser cane training, only 3 were using the aid. Therefore, of the original 26 veterans, only 8 were known to be using an ETA.

Farmer (1978) reported on 18 veterans who completed training in the use of the laser cane. Of these individuals, 11 people were using the laser cane for a period of 2 to 8 years.

A telephone interview was conducted by Morrisette et al. (1981). This study involved 15 veterans who had been trained to use the Mowat Sensor. The length of use varied from 3 to 24 months. All subjects reported the aid to be helpful and continued to use it, although the amount of use varied as well as the particular uses.

Finally, Simon (1984) studied five individuals who received their training at the New York Association for the Blind. Four received training with the Laser Cane and one was trained to use the Sonicguide. The training took place 3.5 to 5.5 years previous to the telephone interview. All five individuals reported that they still used the devices.

These studies represent four separate and independent efforts to determine the success and utility of ETAs. On the basis of personal communication with ETA distributors, it was determined that approximately 3,000-3,500 devices had been sold by 1985. These data, which are anecdotal and crude at best, are not a true representation of the number of devices owned by visually impaired individuals: many of the devices were sold to agencies for training, research, and/or demonstrations, and not to individual users.

RECOMMENDATIONS

On the basis of these findings, the working group makes the following recommendations in the area of information regarding the demography of blind and visually impaired pedestrians.

Surveys of ETA Users and Technology Diffusion

Approximately 3,000-3,500 electronic travel aids have been sold; this represents a small fraction of potential users. Very little is known about who purchased these ETAs, whether they remain in service, and whether training was adequate. Studies designed to evaluate ETA performance have sampled fewer than 5 percent of the 3,500 purchasers of these devices.

It would be helpful for researchers to work toward developing a model of the diffusion of mobility-related technologies, drawing on the general literature on the diffusion of innovations. Current experience suggests that key groups in such a model would include, in addition to the population of potential users of mobility technologies: (1) rehabilitation personnel and mobility specialists, (2) administrators of agencies that provide mobility training, and (3) opinion leaders among blind and low-vision consumers.

RECOMMENDATION: We recommend that a systematic survey of the total or a large sample of ETA purchasers be carried out. This survey should obtain demographic data on purchasers, training history, data on when, how, and how often the devices are used, individual differences in ETA use, and some measure of users' satisfaction with the devices. For a survey of this type to yield broadly useful data, comparison groups should be sampled from among the users of dog guides and long canes; it is very likely that these groups overlap. The study should be designed to estimate the probabilities of multiple device use (e.g., Sonicguide and dog guide) and to reveal the device selection factors that are currently operating in the marketplace.

RECOMMENDATION: We recommend that a study be designed on the diffusion of mobility-related technologies. It could be done through a survey of rehabilitation personnel, mobility specialists, administrators, and opinion leaders among blind and visually impaired consumers. The study should gather data on geographic distribution of potential

users, relevant training and experience, attitudes toward alternative technologies, and interrelations with the other groups. Consideration should be given to the cost-effectiveness of ETAs.

A Normative Data Base

RECOMMENDATION: There is an urgent need for a normative data base that contains information about the entire population of visually impaired and blind people. It should be possible, among other things, to interrogate this data base for information about personal data that indicate readiness for various sensory aids and how sensory readiness changes as a function of maturation and development, from infancy to old age.

A Survey of the Needs of Older Blind People

The prevalence of blindness in the population is greatest among older people. More than half the blind people in the United States today are over the age of 64. Given the growing proportion of people in the older age groups and the particular mobility needs of the elderly, we need to know more about the mobility requirements and preferences of elderly blind and visually impaired people.

RECOMMENDATION: We recommend that a survey be conducted of the mobility requirements and preferences of elderly blind and visually impaired people. The survey should be designed to yield information about the variety, severity, and distribution of their visual impairments and of other sensory, motor, and cognitive impairments that may affect their need for and ability to use mobility aids. The survey should also provide a description of their travel requirements and an indication of the travel techniques and aids that would be most helpful in meeting those requirements.

Review and Analysis of Existing Data Bases

There are no nationally representative data bases designed to provide measures describing the number or characteristics of visually impaired people who have specific mobility needs and problems. The opportunity does exist to obtain information from existing data bases that in the short run and at little expense could provide generally useful information.

RECOMMENDATION: We recommend that existing national (or more local) representative data bases be reviewed and analyzed to extract information on the specific mobility needs and problems of visually impaired people. Likely sources include the ongoing Health Interview Surveys of the National Center for Health Statistics as well as the Work and Disability Study of the Social Security Administration

conducted in 1978. Studies conducted for purposes of public transportation planning might also be likely candidates for the extraction of such information.

Study of Multiple Impairments

On the basis of national studies, we found that more than 50 percent of the severely visually impaired population has at least one additional impairment.

RECOMMENDATION: We recommend that an intensive study be conducted on the interaction of visual impairments with other cognitive, sensory, and physical impairments and their effect on mobility problems.

Development of a Research Agenda

Efforts by engineers and inventors to develop electronic aids for the blind have been sporadic and piecemeal. All too often, when a new aid is developed, it has all the inherent difficulties of previous attempts. The development of specific guidelines and research protocols, which can systematically evaluate aids and make recommendations for future scientists, is needed since funding is so limited. Progress can be made more efficiently and quickly through the accumulation of research findings rather than by individual trial and error.

RECOMMENDATION: We recommend that either a federal agency or professional association concerned with these problems convene an interdisciplinary panel to define a basic research agenda (or minimum data set) that would be widely disseminated to enable researchers working with small samples to produce reports that could permit cumulation of findings across studies. Models for this activity may be sought in the area of research on long-term care and possibly in clinical research areas identified by the National Institutes of Health.

Chapter 3

THE ASSESSMENT OF MOBILITY

The assessment of mobility is a central issue in any discussion of approaches to more effective mobility aids. It is necessary for determining the success or failure of mobility training and the effectiveness of mobility aids and for developing improved techniques and devices for mobility by the visually impaired. In this chapter we review the advances that have been made in the assessment of mobility performance and comment on the further refinements that will be necessary to relate mobility performance measures to the design, development, and use of mobility aids.

INDIVIDUAL CHARACTERISTICS

An individual's mobility performance is affected, of course, by a multitude of predisposing characteristics. Examples of such factors are listed in Table 4. To provide adequate mobility training to a person in need of it, an instructor must consider psychosocial, sensory/motor, perceptual/cognitive, and environmental factors in the choice of instructional technique, the training procedure, and, inevitably, the outcome of the training program.

Past studies have examined the differences in assessment and instructional techniques for specific subgroups of the visually impaired population. For the two-thirds or more of the visually impaired population who are 65 or older, travel needs may differ significantly from those of a younger subgroup. Nonetheless, elderly visually impaired persons have received relatively little attention from the rehabilitation community (Allen et al., 1976, 1977; Carney, 1970; Hubbard, 1969; Shaw, 1970). More attention has been directed to the needs of children (Baird, 1977; Bledsoe, 1963; Ferrell, 1979; Franks and Nolan, 1970, 1971; Goldie, 1977; Hapeman, 1967), the multiply handicapped (Geruschat, 1980; Harley and Merbler, 1980; Primrose, 1981), and the partially sighted (Allen, 1977; Burton, 1976; Cory and Prince, 1976; Hughes, 1967; Quillman, 1977).

TABLE 4 Examples of Predisposing Factors That Affect Mobility

Examples of Psychosocial Characteristics

Individual expectation
 Living situation
 Motivation
 Demographic profile

Sensory/Motor Characteristics

Visual capacity
 Auditory capacity
 Locomotor capacity

Perceptual/Cognitive Characteristics

Ability to utilize echoes
 Spatial awareness
 Cognitive capacity/processing mode

Environmental Characteristics

Urban/suburban/rural
 Weather conditions
 Time of day
 Previous training/learning
 Familiarity

Psychosocial Characteristics

The psychosocial factors that affect mobility have not received the attention they deserve. Those that have been studied include the dynamics of the student-instructor interaction (Fluharty et al., 1976), client motivation (Murphy, 1965), and self-perception (Schulz, 1972, 1977; Welsh, 1972, 1981). Among the factors that have not yet been studied systematically are expectations of success prior to mobility training, family relationships, and living conditions.

Sensory and Motor Characteristics

Sensory and motor capacity are obvious contributors to the eventual success or failure of mobility training. Because most of those who are classified as visually impaired retain some degree of usable vision, efforts have been to determine the residual capacity that characterizes various visual impairments and to determine the capacities of the other senses that either supplement remaining vision or replace lost vision.

Marron and Bailey (1982) have shown that spatial contrast sensitivity and visual fields are better correlates of mobility performance than are standard measures of visual acuity. More research is needed to expand existing knowledge of the relative contributions of residual vision as well as hearing, touch, and gross motor ability to mobility performance.

Perceptual and Cognitive Characteristics

Considerable attention has been paid to the perceptual and cognitive factors on which mobility depends (Foulke, 1971, 1982b). Barth and Foulke (1979) have pointed out the importance of preview, and others have emphasized the importance of sensory training prior to instruction (Mills and Adamshick, 1969). However, a preponderance of the research relative to mobility has had as its objective a better understanding of the effect of blindness on the ability to acquire and use geographical concepts (Franks and Nolan, 1970, 1971; Lockman et al., 1981; McReynolds and Worchel, 1954; Rieser et al., 1980; Worchel, 1951).

There is a need for further study of the ability to acquire and use information contained in echoes (Clark et al., 1975), the interactive functioning of perceptual systems, and the processing mode that is best suited for efficient performance of the mobility task.

MEASURES OF MOBILITY PERFORMANCE

In the past two decades, significant advances in the assessment of mobility were made by researchers who developed objective measures of overt behavior based on operationally defined criteria and observable responses (Armstrong, 1975). These methods, described below, have provided rational and scientifically defensible tools for basic research on mobility and for the objective evaluation of mobility aids and training methods. Unfortunately, these objective measures have not been used widely outside the laboratories in which they were developed. In part, this appears to be due to inadequate documentation of the methods and the need for specialized measuring equipment in order to employ them.

Indirect Measures

Indirect measures of mobility are those that assess the underlying perceptual and cognitive processes that are responsible for overt behavior. Such methods are used to enhance the sensitivity of measurement by providing indices of stress or the demands placed on mental capacity of the pedestrian performing the mobility task. Heart rate measures obtained during mobility, for example, have provided valuable data concerning the psychological stress experienced by the blind traveler using different aids and performing in various

environments (Heyes et al., 1976; Peake and Leonard, 1971; Tanaka et al., 1981; Wycherley and Nicklin, 1970). The secondary task technique was used by Shingledecker (1983) to assess the reduction in the information processing demands of travel as a function of route familiarity and previewed information. This technique involves having the pedestrian engage in a secondary, unrelated task while negotiating a route; it was also used to perform a performance benefits/mental costs evaluation of mobility aids.

Despite the potential of these indirect measures of performance, very little has been done in recent years to further their development. However, several methods, such as analysis of the P300 component of event-related brain potentials (ERP), have proven useful as direct measures of the mental workload demanded by system design tasks and might prove useful in basic mobility research and ETA evaluation as well.

A majority of the performance assessment work done by mobility specialists and many applied researchers is accomplished through the use of subjective assessment methods. Unfortunately, these methods have often consisted of informal and global expert judgments. Even when simple rating scales and checklists have been used, examination of subjective approaches has revealed evidence of rater bias and low interjudge reliability (Airasian, 1973; Nye, 1973).

Indirect measures correlate with direct measures of the mobility task. That is, they are influenced by factors other than the components of the mobility task and may include such measures as a comparison of heart rates during travel in familiar and unfamiliar environments or the personal assessment of confidence under varying circumstances. Indirect measures of mobility may be further divided into subjective and objective measures. Subjective measures include ratings by subjects of their ability to perform a task and to recover from errors and self-reports of mental workload. Objective measures include stride length, secondary task performance, veering tendencies, and the like.

Direct Measures

Direct measures used to assess mobility performance measure specific aspects of mobility, such as obstacle detection or a mobility specialist's subjective judgment of mobility skills. Examples of direct, objective measures of mobility are found in Table 5. Direct subjective measures include expert judgments (Airasian, 1973), self-reports of the quality of performance, checklists and rating scales (Genensky et al., 1979; Wurzbarger, 1965), family reports, and estimates of personal satisfaction (Airasian, 1973; Bailey et al., 1984).

The direct observation and measurement of behavior often requires expensive equipment and technical training and may prove impractical in many settings outside the laboratory. A more practical approach in these settings would be the use of instruments that rely on subjective judgments, such as ratings scales, but instruments of this sort require

TABLE 5 Examples of Direct, Objective Measures of Mobility

Safety	Obstacle contacts
	Unsafe veering
	Fail to detect step-down
	Fail to detect step-up
	Inner shoreline body contact
Efficiency	Walking speed
	Continuity of travel
	Navigational errors
	Veer
	Route departures
Travel Frequency	
Travel Distance	
Travel Familiarity or Difficulty	
Device/Sensory System Specific Measures	Sign detection
	Search time
	Reading time
	Surface structure/texture determination
	Drop-off detection
	Directional determination
	Distance determination
Ratio of Independent to Sighted Guide Travel	
Object or Landmark Detection	

psychological scaling before they are suitable for use, and to date little effort has been made to meet psychometric requirements.

Outcome Measures of Successful Mobility

In addition to objective measures of the performance of the mobility task itself, a thorough assessment of orientation and mobility must include measures of variations that are correlated with performance variables (Darling et al., 1977; Gillman and Simon, 1980; Morrisette et al., 1981). These correlates are what might be called context variables. They make up the background against which the mobility task is performed. Included are such factors as social awareness and social skills, perceptual and cognitive strategies, and spatial knowledge.

Personal satisfaction with the quality of life may be the most global and significant correlate of mobility, because mobility is a prerequisite for so many of the activities that give meaning to life (Blasch and Apple, 1975; Weisberger and Hall, 1985). Few studies have incorporated these issues systematically as design components.

ASSESSMENT OF MOBILITY

Assessment of Mobility Aids

Many of the travel aids that are currently or potentially useful to blind and visually impaired pedestrians are based on the application of electronics and optics technologies. In response to needs expressed by the military service as well as the general public, we can expect both of these technologies, including areas such as the study of artificial intelligence, to make significant contributions to solutions to mobility problems (Deering, 1985; Tou and Adjouadi, 1985). The high cost of travel aids that make use of new technology, no matter how effective they might be, seriously limits their development. High cost may in part be a consequence of the protection from competition afforded by patents. For example, the Mowat Sensor, and the Sonicguide are both patented inventions that can be produced only by authorized manufacturers. However, patents expire and other manufacturers may enter the fields and may produce a greater variety of less expensive aids. A recurring criticism of the way in which travel aids have been developed is the lack of communication between their developers and such groups as mobility specialists and specialists in the evaluation of performance. The result of this failure of communication is that the conception, development, and production of sensory aids is not guided by full awareness of the needs of those who are expected to use them, by a clear definition of their strengths and weaknesses, or by an adequate understanding of the nature of the training their mastery will require (Brabyn, 1985; Dodds, 1985; Dodds et al., 1983; Spungin, 1985; Warren and Strelow, 1984b, 1985).

A Standardized Method for Assessing Travel Performance

The field of mobility assessment is currently in a state of disarray. There is an absence of controlled studies of mobility skills. There is an incomplete understanding of the effects of electronic travel aids, training methods, and other factors on mobility. This situation is due in part to the fact that the field has failed to adopt a standardized method for assessing travel performance.

One of the reasons for the lack of a common assessment method rests in the fact that assessments are performed by a variety of individuals to meet diverse goals. The basic research scientist, for example, may use performance measures to test hypotheses about the nature of the perceptual and cognitive processes that underlie travel behavior. The applied research scientist might employ performance measures to evaluate

the efficacy of a particular electronic travel aid. Finally, the mobility specialist may use performance measures to evaluate a student's progress, to formulate training goals, or to develop recommendations for the prescription of a particular aid. The same assessment method does not necessarily suit all situations. It is not really surprising, therefore, that these professionals would select different measures to achieve their particular objectives.

The differences among measures--such as those described in Table 5 and elsewhere in this chapter--can be appreciated by considering their theoretical and practical dimensions. Preferred measures are those that would be sensitive to changes in the individual's capabilities, that can be reliably measured, and that validly index the skill being assessed.

Performance assessment measures should provide information about overt behavior, such as the quality of the travel skill displayed overtly by the pedestrian. Such measures may be based on expert judgments or on objective performance data that define safe, efficient, and purposeful travel. These goals can be operationally defined in terms of walking speed, obstacle contact, navigational accuracy, and various productivity indices. Ideally, such measures should be "device-free," that is, they should be applicable to an individual's performance regardless of the travel aid used. However, some device-specific measures may be justified if they are used to draw inferences about some objective aspect of travel skill. For example, shoreline cane contacts or efficient sign-reading with a telescope are valid objective indices in an outdoor travel evaluation.

Performance assessment measures should also describe covert processes that account for observed travel behavior, such as the psychological cost of mobility under different travel conditions or in the use of various travel aids. Such information may be obtained from subjective reports, behavioral observations, or electrophysiological measurements. Historically, such measures have included rating scales to assess travel ease and confidence, heart rate parameters to assess stress levels, and secondary tasks performed in conjunction with mobility to assess the reserve information-processing capacity of the traveler.

An important feature of indirect measurement is its ability to increase the overall sensitivity of the assessment procedure by detecting differences that are not reflected in general measures of overt performance. For example, two travel aids may provide equivalent overt performance but, in one case, the pedestrian is performing at the limits of his or her information-processing capacity. It is important to realize that direct and indirect measures are not mutually exclusive alternatives in the assessment of mobility performance.

Finally, an inescapable fact regarding the assessment of mobility is the necessity to isolate the individual components of mobility skill and to synthesize them once more into a global evaluation of total performance. From a practitioner's point of view, the emphasis must be placed on whole-skill measurement.

RECOMMENDATIONS

It is clear from the information presented in this chapter that there is a need to develop a framework or theory of mobility that identifies the perceptual and cognitive components of mobility and that makes explicit the extent to which mobility is influenced by such factors as training, travel aids, the nature of the environment in which the mobility task is performed, and social variables. We need to develop consistent techniques and measures of mobility performance so that experiments can be replicated and their results compared. Finally, there is a need for improved experimental designs, which reflect more careful attention to such issues as the use of experimental controls, sample size, statistical analysis, and the generalizability of the results of experiments. In order to attain these goals, we make the recommendations that follow.

Standardized Measures of Mobility Performance

Accurate and practical assessment of the performance of blind and visually impaired pedestrians is urgently needed. It is not likely that a single scheme that is appropriate to all situations can be developed, but the development of several coordinated methods is a realistic objective. Standardized procedure for evaluating mobility aids and a standardized procedure for assessing and comparing the performances of subjects with different kinds and degrees of visual impairment would be immediately useful to researchers and practitioners alike. Explication of these procedures should include statements of the rationale for all of the instruments involved in assessment, and complete documentation should be provided for each instrument.

There is also a need to develop additional indirect measures of mobility performance. These might include measures of the performance of a secondary task, such as the task of conducting a conversation with a companion while traveling on foot independently. Because fluctuations in the performance of a secondary task often permit inferences concerning relatively subtle changes in the performance of the primary task, important differences in task performance can be detected only by indirect measures.

RECOMMENDATION: Efforts to develop improved methods for measuring performance of the mobility task should be a research priority for federal funding agencies involved in this area. Research should be undertaken immediately on the development of improved objective measures of mobility performance, drawing on past efforts in England, the United States, and New Zealand.

Simulation Methods

There is a need to develop simulation environments to study mobility performance and its assessment. Such simulations, while

preserving fidelity to the real world in important respects, permit experimental controls that cannot be enforced in the real world. We will not make significant progress in assessing the performance of blind travelers, evaluating training methods and travel aids, and designing improved travel aids until our efforts are guided by a comprehensive theory of mobility that has been confirmed by the results of numerous experiments, and many of these experiments can be conducted more effectively and efficiently in a simulated environment than in any other setting. However, the construction of simulated environments is an expensive undertaking, for which federal assistance is not likely. Simulated spaces must be large enough to permit realistic performance of mobility tasks. Such spaces should also have the physical and acoustical characteristics of the surfaces and space an individual will encounter in the real world (Shingledacker and Foulke, 1978).

RECOMMENDATION: Investigators should more frequently use simulated environments to study mobility performance and its assessment. The private sector could contribute to the development of simulation methods through the development of simulation technology.

Improved Field Assessment Techniques

Assessment techniques used in the laboratory often require expensive instruments and facilities and technically trained personnel. Consequently, their use in field studies is not practical. More subjective techniques such as rating scales, expert judgments, and the like, can be made serviceable if they are validated by the application of psychometric methods; this work is yet to be done.

RECOMMENDATION: Improved field assessment techniques should be developed through strengthened support for research in which psychometric methods are used to develop rating scales and other measuring instruments of that type.

Technology Benchmarks

As developments in technology continue, new travel aids, which go beyond the current state of technology, will be built. As a necessary step in their development, a rigorous comparison will be needed of the performance facilitated by travel aids now in use. The information yielded by such comparisons is essential in deciding about the actual contribution made by new travel aids to the performance of the mobility task.

RECOMMENDATION: Because progress in the development of travel aids and better methods for their assessment will depend in part on making individuals in many different disciplines more aware of the current state of mobility problems, we recommend that communication among such groups as engineers, psychologists, mobility specialists, teachers, and

consumers be facilitated. Federal funding agencies can play a role by actively funding conferences and workshops to further the development of performance comparisons of new and existing technologies.

Training Programs

It is not sufficient to assess the improvement in performance made possible by the use of a travel aid. We must also do a more effective job of assessing the improvement in performance that is attributed to participation in a training program. Furthermore, we must do a more conscientious job of evaluating the programs in which blind pedestrians are trained and the programs in which mobility specialists are trained.

RECOMMENDATION: We recommend that academic departments in which mobility specialists are trained and the federal agencies from which they receive support cooperate in providing more training for students in the assessment of performance.

Chapter 4

PERCEPTUAL, COGNITIVE, AND ENVIRONMENTAL FACTORS

In order to build more effective aids to mobility, we must gain a much better understanding of the mobility problem than we currently have. We need to know what spatial information blind and visually impaired pedestrians need, how spatial information should be displayed, to what sense or senses, and whether preprocessing of the data acquired by electronic travel aids will be required. This chapter deals with the perceptual, cognitive, and motor functions of the blind and visually impaired pedestrian who performs the mobility task and identifies the questions that must be answered in order to specify the functions of a successful travel aid.

THE MOBILITY TASK

Mobility is undertaken with a purpose in mind, that of reaching a destination, and, if pedestrians are to reach destinations, they must know not only where those destinations are, but also where they are themselves. They must be oriented, and they must be able to maintain the currency of orientation as they move through space.

Performance of the mobility task demands what Poulton (1954) has called an open skill. Because the task is performed in an environment that is changing and only partially predictable, its performance must be guided by feedback, including internal somesthetic feedback and external feedback in the form of information acquired from the space in which the task is performed. Furthermore, the requirements of the task are not usually adequately specified by information acquired from the space in which the task is performed while it is in progress, and the blind pedestrian must supplement this information with information retrieved from memory.

PERCEPTUAL, COGNITIVE, AND MOTOR FUNCTIONS

Pedestrians acquire some of the information they need for the mobility task directly from the space in which the task is performed while it is in progress, by way of perception. They also acquire some of the spatial information they need by consulting their memorial

representations of the space that they have experienced and their knowledge of generalized aspects of spatial structure. Hereafter, we use the term perceptual information for the information acquired directly from the surrounding space, and the term cognitive information for the information retrieved from memory in order to perform the mobility task. It should be stressed, however, that this distinction is more an organizational convenience than a theoretical division--perceptual issues merge gradually into cognitive issues, and no sharp separation is possible or desirable (Strelow, 1985).

Perceptual Information

Perception informs pedestrians about the layout of the space within the range of observation. Through perception, they discover where paths are and where they are not. They discover obstacles, and, provided they have had enough experience with a space to have some memory of it, they may identify useful landmarks.

Perceptual information is distributed over time as well as space, and perception of temporal changes may be as important as perception of stable spatial structure.

Physical Features

In describing the contents of space, it is customary to mention objects. However, for our purposes, the term object is not inclusive enough. What is needed is a term that denotes any part of a space that can be distinguished from other parts and remembered. The term feature is more appropriate because it is of more general significance. Thus, a parking meter, which would usually be called an object, is a feature, but an opening between trees, a curve in the path, a slope, or an irregularity in the surface underfoot, if they are discriminable, are features, too. The path segments in the currently observable space, which, if remembered, become the elements that are integrated to provide knowledge of layouts, are also features. Pedestrians need to know what features are in space and where they are, because features may be obstacles, and, with learning, may become landmarks (Armstrong, 1977; Foulke, 1983).

Many features of the environment make characteristic sounds, and because pedestrians can form associations between these features and their sounds, sounds can become meaningful. Consequently, such features can often be identified by the sounds they make. For instance, because car horns make sounds that are rarely confused with other things, the sound of a car horn warrants the inference that there is a car at the locus of the sound source. However, the acoustical energy that is perceived as a car horn can contain no information about spatial extension, and so it cannot specify the size and shape of the car. As a matter of fact, unless the sound of the car horn is so distinctive that it can be distinguished from all other car horns and can therefore be associated with a particular car, the sound of the car horn can only identify the category that includes those things we call cars.

Even when an association between a feature and its sound has been formed, the sound does not, in most cases, provide a dependable means of identification, because the sound and the feature with which it is associated are usually not continually coincidental. For example, because a car horn is silent most of the time, it does not provide a dependable indication of the car's presence and position.

Events

Events, such as movement, have temporal extension and must be perceived by a system that is capable of temporal analysis. In order to perform the mobility task, pedestrians must know not only what things are in space and where they are, but also whether they are in motion and, if so, how fast and in what direction they are moving. For example, blind pedestrians sometimes regulate their own direction of motion by keeping it in agreement with their perception of the direction of motion indicated by the sounds of moving traffic in a parallel street. Both blind and sighted pedestrians must use estimates of the rate and direction of motion of moving things in order to make decisions about when and when not to move and, if to move, in what direction and how fast. Blind pedestrians get the information they need for these decisions by hearing audible things in motion. Sighted pedestrians probably get some information by hearing audible things in motion, too, but they undoubtedly get more information of this kind by seeing visible things in motion.

Spatial Zones

In order to get the spatial information they need, pedestrians must know where in the surrounding space to find it. If blind pedestrians are using mobility aids for that purpose, those aids must be so designed that they can examine the spatial zone or zones in which the information is to be found.

This is an important issue. One of the decisions reflected in the design of any mobility aid is a decision, implicit or explicit, concerning the spatial zone to be examined. That decision, once made, sets some limits on the kind of information that can be acquired.

There are four primary zones in which important information is found:

(1) The travel surface. Blind pedestrians need information about the surface on which they walk, including changes in surface texture, particularly drop-offs or step-ups and potholes or other hazards that may occur in the surface.

(2) The path ahead. Blind pedestrians need information about obstacles that may occur in the spatial area through which they will be moving.

(3) The adjoining space. Blind pedestrians may need information about features of the space that adjoin the travel path, particularly

so that such features may serve as landmarks. The adjoining space is that which is immediately perceptible to both sides of the intended travel path as well as, possibly, overhead.

(4) The extended space. Sighted pedestrians often need information about the larger space in which they travel, whether there is a bridge or a building ahead, for example. Blind pedestrians have the same need, although the limit of their immediately perceptible space is often restricted to the limits of the cane or other travel aid. Serious attention must be given to the need for blind pedestrians to have access to the important features of the extended space in which they travel.

Perceptual Anticipation

Numerous experiments (Barth, 1979; Crossman, 1960; Hershman and Hillix, 1965; Levin and Kaplan, 1969; McLean and Hoffman, 1973; Poulton, 1954) have demonstrated the dependence of skillful mobility performance on the ability to anticipate behavioral requirements by observing the characteristics of a situation in advance of the time at which some action will be required. It is useful to distinguish two kinds of anticipation, perceptual anticipation and cognitive anticipation (Barth and Foulke, 1979; Foulke, 1982; Poulton, 1952). Perceptual anticipation is made possible by direct observation of the space in which it is performed while the task is in progress. Blind pedestrians who are informed in advance by perception that a curb is coming up have time in which to prepare for the sequence of movements that, when executed with proper timing, will ensure that the curb is dealt with successfully. Cognitive factors are discussed in the next section.

The Sufficiency of Perceptual Information

If pedestrians can gather enough perceptual information while the mobility task is in progress, if it is relevant and sufficiently accurate and specific, and if it can be acquired soon enough to allow time for planning the behavior it dictates, then perceptual information can regulate task performance. The spatial information that can be acquired by visual perception usually meets these requirements. However, because blind pedestrians, using the perceptual processes available to them, acquire less spatial information than sighted pedestrians observing the space in which they are performing the mobility task as they are performing it, they must depend more heavily than sighted pedestrians on information retrieved from memory.

Cognitive Information

There is, at present, a lively debate over how spatial patterns are represented in memory (Anderson, 1978; Corballis, 1982; Pylyshyn, 1973). Current research suggests that cognitive representations are hierarchical in structure; that information is clustered into chunks

throughout these hierarchies; and that the clustering exhibits both spatial (analog) and non-spatial (semantic) attributes (Hirtle and Jonides, 1985). Many experiments show that memory is selective with regard to the spatial information it stores (Appleyard, 1970, 1976; Brewer and Treyens, 1981; Evans et al., 1981; Lynch, 1960; Shagen, 1970; see also Strelow, 1985, for a discussion of these and related issues). It seems reasonable, therefore, to regard the cognitive representations constructed by pedestrians as they gain experience with the spaces in which they travel as schematic in character. Just as a road map preserves the information needed by travelers to find their way through a network of roads, while omitting most of the detail that would be present in an aerial photograph of the territory described by the map, it is reasonable to hypothesize that pedestrians preserve the information they need to move through space independently and safely and to reach their destinations, while omitting the abundance of irrelevant detail they may have observed.

Memorial representations of perceived features and events are the elements that are integrated to form cognitive representations. Cognitive representations contain information not immediately present in the elements from which they are synthesized. For instance, a cognitive representation may supply knowledge of the shape of an object that is too large to be observed by touch from one position; for the shape to become evident, it is necessary to integrate haptic observations made from different positions at different times. Likewise, the spatial relationship of a number of things perceived separately will not be evident until it has been revealed by integrating them. Thus, some of the information that is essential for pedestrians is the product of cognitive processes.

In most of the spaces through which pedestrians move, there are affordances--that is, movement along some courses is easy, while movement along other courses is difficult or impossible. These affordances are simply paths. The paths in a space usually intersect. Intersections are connected by path segments. The entire collection of path segments and intersections in a space constitutes its path structure. A route is a sequence of connected path segments that affords passage from a starting place to a destination, and in most spaces, a destination may be reached by more than one route.

The layout of a space is, broadly speaking, the arrangement of all of the things in that space whose locations are fixed. It is not usually possible to perceive the pattern formed by the paths in the spaces through which pedestrians move, because in most cases not enough space can be observed from one position and at one time to make the pattern evident. Consequently, the cognitive representations are often syntheses that have been achieved by integrating spatial information resulting from observations made from different positions and at different times. Evidence presented by several investigators (Appleyard, 1970; Beck and Wood, 1976; Lynch, 1960) indicates that integration is not always complete and that cognitive representations often exhibit discontinuities, oversimplifications, and errors. The completeness and accuracy of the integration probably depends, in part, on the extent of the space that can be observed from one position and at one time, as well as on the nature of the individual's experience in the space.

Because blind pedestrians can observe much less space from one position and at one time than sighted pedestrians, they must do more integrating, and the syntheses they achieve are accordingly less accurate and complete. Furthermore, because they cannot make use of many of the landmarks that keep sighted pedestrians oriented in the larger spaces, the blind may have to place more reliance on cognitive representations than sighted pedestrians.

Ordinarily, route knowledge includes landmarks (e.g., distinctive characteristics of the surface under foot or features in the spaces bound by path segments) which pedestrians use to confirm their route positions. However, in the absence of other information, pedestrians can, with just the spatial knowledge contained in a cognitive representation, traverse a route without error. Imagine a route like that learned by a white rat in a maze. Path surfaces are smooth and undifferentiated. The spaces bounded by path segments are devoid of distinguishing landmarks. Nevertheless, with practice the route can be learned. What is learned is a sequence of correct actions at choice points (turn left, turn right, go straight ahead). Pedestrians who rely on this kind of knowledge alone must remember their actions at preceding choice points in order to know what to do next. If they have a lapse of memory, they will be lost. If for some reason they stray from the path, they will also be lost, because their cognitive representation does not include any landmarks that could be used for geographical orientation. Furthermore, with such a simple representation they cannot select an alternate route if they find a path blocked.

Blind pedestrians rarely find themselves in situations in which they must depend entirely on route knowledge with no landmarks whatsoever, although a network of corridors in a large hotel can come close to providing this situation. However, they often find themselves in situations in which landmarks are scarce, and, when this is so, they must depend on more generalized or stereotyped cognitive representations.

Most people spend most of their time in built environments, and in built environments certain patterns are repeated over and over again. For example, in cities, streets cross other streets, and they often intersect at right angles. Many of them have been given contours that assist drainage: from the center, they slope downward to either side. They are usually bounded by curbs, so that one must step up in order to pass from the street to the adjacent land. On both sides of streets are frequently found sidewalks, and in residential areas these sidewalks are often separated from the streets by grassy verges on which trees, utility poles, and lamp posts are scattered. Because constructed environments exhibit pervasive reiteration, the cognitive representation incorporates what may be regarded as spatial stereotypes. These stereotypes are the generalizations on which pedestrians can base predictions concerning what they will encounter in spaces not previously experienced. Of course, actions will be more effective if they are mediated by the information acquired by direct observation of the space in which the task is performed or by consulting an accurate schematic representation of that space, but, in the absence of better information, these generalizations are useful. The extent of their actual use, however, is an unresearched issue.

When pedestrians enter new spaces, they have no schematic representations of those spaces to consult, and, if they are blind, the information they can acquire by observation on first encounter will generally not be sufficient to direct their actions. Their only recourse is to rely on relevant spatial stereotypes until they can integrate enough direct observations, made serially, to form accurate schematic representations. Recourse to spatial stereotypes is also available to sighted pedestrians, but the perceptual information provided by visual observation is generally sufficient to guide their performance, and they do not have as much need to supplement it with cognitive information. Thus, on first encounter with unfamiliar space, the performance of the blind pedestrians is relatively poor but improves with practice, whereas the initial performance of sighted pedestrians is relatively good and does not improve much with practice (Hollyfield, 1981).

Perceptual-Motor Skills

Of course, any discussion of mobility skills would be incomplete without attention to the set of perceptual-motor skills that enable the blind pedestrian to maintain an appropriate relationship between his or her body and the path immediately ahead. Developmentally, muscle tone, range of motion, flexibility, crawling, creeping, and upright walking are examples of important prerequisite motor behaviors that enable blind persons to move about. Blind pedestrians need such gross motor skills as strength, endurance, coordination, and balance in order to perform the mobility task efficiently. In addition, fine motor skills are needed to explore an object, use an orientation aid, or use a mobility aid such as the long cane or an ETA.

In performing the mobility task, blind pedestrians must constantly update their direction and distance to relevant features of the environment. Several orientation skills (Hill and Ponder, 1976), along with corequisite perceptual motor skills, are used to accomplish effective spatial updating. For example, consider the skills of establishing alignment, maintaining a straight line of travel, executing turns, and judging distances. All these skills facilitate spatial updating. However, good posture, gait, coordination, and walking speed are crucial to execution of these skills. In addition, the proprioception (body awareness/image), tactile (use of the hands, feet, and posterior plane of body), auditory (localization and judging trajectories), and kinesthetic (time/distance estimation through movement) senses are integral to performing the above orientation skills.

The process of spatial updating, along with its complementary skills, also facilitates the acquisition of spatial layout knowledge (object-to-object relationships). Learning a large novel space requires the concurrent use of the previously mentioned orientation and perceptual-motor skills, along with using systematic search patterns, establishing landmarks, and identifying clues.

MOBILITY SKILLS

Having outlined the nature of the perceptual information and cognitive processes available to the blind pedestrian, we now describe how the information from these sources is put to use in order to deal with a specific mobility task. These applications of knowledge about the environment can be conceptualized as a set of mobility skills, each of which has its own developmental sequence and degree of importance for an individual blind pedestrian. Before describing these mobility skills one by one, however, it is useful to keep in mind several common features.

First, the goal motivating the application of each skill is the same: successful solution of a mobility problem. But success, as we stated earlier, includes much more than just the act of reaching point B from point A. One mark of a successful traveler is the ability to reach point B in a way that minimizes to an acceptable degree the physical and psychological risks associated with travel. As Foulke (1971) has stated, the goal is to move safely, gracefully, comfortably, and efficiently from A to B. The mobility skills described below are all strategies that make obtaining this goal considerably more likely.

Second, the application of these specific mobility skills is particularly critical for blind pedestrians due to the limited degree of perceptual anticipation possible in the absence of vision. Sighted pedestrians who can gather perceptual information in ample time for the guidance of their locomotor behavior need not rely so heavily on inferences about the environment. What sighted pedestrians can see for themselves, blind pedestrians must often infer, and many if not all of the mobility skills described can be thought of as types of inferential reasoning about what is present in the environment and how one should move as a result.

In the sections that follow we describe the mobility skills, or applications of knowledge, that are to a greater or lesser extent available in the repertoire of the blind traveler. For purposes of discussion these skills are divided into two major categories: (a) skills that depend on the application of general knowledge about environments and (b) skills that depend on the application of knowledge about a specific environment. Obviously, one implication of this division is that the first set of skills will have a particularly important role to play in solving mobility problems in unfamiliar environments.

Applications of General Knowledge

Inferences Based on Spatial Stereotypes

As noted earlier, one type of information available in the knowledge base is a set of expectations about what a given environment should be like. These expectations may be characterized as probability statements that arise through a variety of sources, including one's own previous spatial experience and direct tutelage by travel instructors. These

expectations are applied by blind travelers, sometimes successfully and sometimes not, to help them plan the locomotor behavior that will be most likely to advance them toward their goal. For example, the expectation that streets in an urban setting will be laid out in a grid pattern may lead the blind pedestrian to infer that a 90-degree turn at a corner will allow him or her to maintain the appropriate relationship to the sidewalk. The feedback that the traveler obtains once this inference is acted on will obviously enter the data base of knowledge on which the traveler will depend for a subsequent trip through that environment.

Inferences Based on Logical Principles

The traveler for whom minimizing effort is a major criterion for successful travel may learn to apply various logical principles. One example is a technique called baselining, which is useful in crossing open spaces such as going from a corridor across an open hotel lobby to the continuation of the corridor on the other side of the lobby. In baselining, a decision is made to steer toward a point that is certain to be wide of the target in one direction (e.g., to the right). Once that point is reached, the traveler can be sure what direction of travel (e.g., left) will result in reaching the goal. Had the traveler instead chosen from the start to try steering directly toward the target, a failure to hit the target accurately would leave him or her uncertain about which direction to move to regain the desired path. Such a cognitive strategy can be applied in a variety of environmental situations in order to increase the probability that the target will in fact be found.

Applications of Specific Knowledge

Landmarks

At the simplest level, landmarks are features that, when recognized, serve only to assure travelers that they are on course. At this level, landmarks need not serve an orienting function. In fact, they need not even have been observed before. Knowledge of such landmarks may have been conveyed by maps, pictures, spoken or written words, and so forth.

At a higher level, the identification of a landmark that is on or close by a path segment that is part of a known route may serve as confirmation of one's current position. For example, the unusually sharp curve in a path or the distinctive bump in a sidewalk caused by a tree root underneath may tell blind pedestrians who have traversed the route a number of times exactly where they are.

A landmark is most useful when its relationship to other landmarks in the same space is known. Pedestrians whose spatial knowledge includes a knowledge of the interrelation of several landmarks establish more than their route positions by recognizing one of those landmarks. They also establish their positions in the entire space that encompasses

the interrelated landmarks. Although they have probably acquired a good deal of route knowledge and knowledge of path structure in the course of learning landmarks and their interrelations, they could, if necessary, find their way through the space that encompasses the interrelated landmarks without drawing on their knowledge of path structure and routes. It is this aspect of landmarks in which most blind pedestrians are lacking.

The value of a landmark is, in part, a function of the extent of the space in which it is observable. The skyscraper just north of the main shopping district that can be seen for miles in all directions allows sighted pedestrians who know about it to maintain orientation in a very large space; as a result of its presence, they need not learn about many other landmarks that cannot be observed from so great a distance. Furthermore, pedestrians need not ever get close to a landmark of this type. It will still serve its orienting function from a distance. The implication is that the number of landmarks pedestrians need to maintain orientation varies inversely with the extent of the space within which landmarks are observable.

The extent of the space within which the landmarks used by blind pedestrians can be observed is relatively small. They can identify distinctive characteristics of the surface underfoot, they can find things within arm's reach or the reach of the cane or ETA, they can find things a few feet off the path by echo location--but they are largely unaware of the contents of the spaces bounded by the path segments along which they walk. They must, instead, depend on a large number of landmarks that denote small segments of the space.

Clues

As the blind pedestrian travels through a specific environment, he or she will inevitably encounter objects or events that act as clues to guide decisions about the appropriateness of a particular movement. The skill that is desirable for the blind traveler includes both the ability to identify the objects or events and the ability to draw the proper inferences from them. For example, from the sound of water splashing the blind traveler might infer the existence of a puddle in the street about to be crossed. Clues furnish information whose bearing on the mobility task is not completely certain; inference must be brought to bear to make use of this information.

INDIVIDUAL DIFFERENCES

In order to understand the mobility task and the human skills and abilities enlisted in the performance of the task, it is necessary to consider the individual differences among those who will be performing the task. With regard to blind pedestrians, those differences are numerous and of considerable importance and magnitude. There are those factors on which all humans vary, such as intelligence and motor facility, which affect the performance of any of the tasks in which

humans engage. Beyond this, there are individual differences brought about by the blindness that is responsible for the mobility problem.

Risk Estimation and Risk Taking

Humans vary widely in regard to their ability to estimate risk. Some seem unaware of the risk that may be inherent in a situation. Others characteristically overestimate risk. In addition to the matter of estimating risk, there are those who seem to court risk and those who choose courses of action intended to minimize risk, regardless of the personal price in loss of freedom, missed opportunity, and so forth. Those who perform the mobility task face genuine risks, such as the risk of getting lost, the risk of falling on a slick surface or down a flight of stairs, and the risk of being hit by a car. For the most part, blind and sighted pedestrians face the same risks, but the probability of engaging the dangers is greater for blind pedestrians. They have less ability to acquire from the surrounding space the information they need to assess risk; consequently, they must contend with a higher level of uncertainty. They also have less ability to acquire information on which to base actions that avoid risk.

The seriousness of these problems can be reduced by training of the sort provided by mobility specialists and by the use of effective travel aids. There should be a positive correlation between the ability of blind pedestrians and their willingness to travel in unfamiliar situations; evidence presented by Russo (1985) suggests that this is the case. However, risk can also be reduced by restricting travel to familiar situations; this strategy is adopted by more blind pedestrians than those who have a vested interest in the ability of blind persons to travel independently would care to admit. There are blind pedestrians who, like gamblers at a casino, seem to enjoy risk and seek the challenge of traveling in unfamiliar situations, but most blind pedestrians, including many apparently skillful travelers, learn routes to the places they must reach with some frequency and avoid unfamiliar situations. They find acceptable the risks they incur when their performance is regulated by both perceptual and cognitive information, but they are reluctant to accept the risks they incur when only perceptual information is available. Thus, travel in novel environments may be avoided.

Early Versus Late Blindness

There is evidence that age at onset of blindness is an important variable in determining the ability of blind pedestrians (see Warren et al., 1973; Warren and Kocon, 1974). The literature indicates that those who have had vision for several years before becoming blind acquire the concept that there is a spatial relationship among the objects of experience, a relationship that can be grasped and remembered. Once this concept has been incorporated as a part of the cognitive operating system, it is available for organizing spatial

experience, even when vision is no longer a perceptual resource. Those who are blind from birth or who have lost vision before having had the opportunity to acquire this concept, are not served by the perceptual system that is most effective in providing information about the spatial extension of features or about the relationship among features in space. They must rely on other perceptual systems that are not as well suited for acquiring information of this kind. For example, although the reach of the auditory system permits the observation of a considerable extent of the surrounding space, acoustical stimulation does not generally contain reliable information about the spatial extension of spatial features, and most spatial features are not associated with distinctive sounds that could disclose their distance and direction from the observer. Although the haptic system can provide information about the spatial extension of spatial features, physical contact is a requirement for perception. The reach of the haptic system is therefore too limited to permit direct perception of the relationship among many important spatial features. It may be that appropriate perceptual experience can provide compensation for these perceptual limitations, but, in the absence of such experience, those who are congenitally blind may exhibit a reduced ability to grasp spatial relationships that persists throughout life. The possibility that early use of mobility aids to serve as environmental sensors (Strelow and Warren, 1985) may help overcome this limitation is an exciting one that should be pursued.

Overprotection

It is understandable that those responsible for the care of blind infants will want to protect them from harm and will imagine that movement through space without vision is dangerous. Guided by this premise, many parents restrict the activity of blind infants, but, by so doing, they deprive them of the perceptual experience that could lead to spatial comprehension. Beyond this, they may be making it difficult for blind infants to learn where to turn for the stimulation that contains the information they need to deal effectively with the world in which they live. As the work of Fraiberg (1977) suggests, infants who are perceptually deprived in this way may have difficulty in distinguishing themselves from other features in the surrounding space and in acquiring the concept of object permanence. Because they are relatively inattentive to stimulation in the surrounding space, they do not have the perceptual experience that could compensate for the reduced ability of the perceptual systems available to them to provide information about space.

Neurological Damage

It is commonly believed by teachers, mobility specialists, and others who have the opportunity to observe the mobility of blind children that those who are congenitally blind by reason of retinopathy

of prematurity (ROP; previously called retrolental fibroplasia) are much worse off in terms of mobility than other blind children (except the multiply handicapped blind child). There is only sparse evidence bearing on this issue (e.g., Fletcher 1981). If it is true, then there is the possibility that the condition responsible for the retinal destruction that characterizes ROP may also be responsible for other damage in the central nervous system that is too diffuse in character to be directly observable. That damage may also be too diffuse to have clearly observable behavioral consequences from which it might be inferred but may nevertheless be responsible for the poor spatial ability of individuals who are blind because of ROP.

Remaining Vision

Most of those who fall within the definition of legal blindness have some remaining vision, and that remaining vision may be very useful in acquiring information that facilitates performance of the mobility task. Even when only light perception remains, the ability to detect shadows can provide useful information. Macular degeneration may reduce central acuity enough so that the affected individual is regarded as legally blind, yet the individual may have relatively good peripheral vision. One of the important uses of peripheral vision is the detection of movement, and information about objects in motion is an important kind of information for any pedestrian (Raymond and Leibowitz, 1985). Individuals are legally blind for many reasons, and the cause of a visual impairment is an important determinant of the spatial information that can be acquired with the remaining vision.

Conclusion

The purpose of the discussion has been to make the point that any mobility aid or training effort must be applied in the context of individual differences, and these individual differences may play a major role in determining the effectiveness of the mobility aid or training effort. If we are to apply what we know about mobility to the solution of human problems, our application must be guided by a better understanding of the differences among the individuals who might be able to use what we know to their advantage.

RECOMMENDATIONS

Research involving blind individuals, whether on mobility or other topics, has unfortunately received far too little sustained attention by experienced investigators. There are, of course, notable exceptions, but promising leads have not been pursued, and the research literature is choppy and fragmented as a result. Perhaps the most important recommendations, therefore, in this area are that support and encourage-

ment must be provided for sustained research programs and that means should be provided for drawing young research scholars into mature and sustained research settings.

Research needs in the perceptual and cognitive areas of mobility are considerable. It is not the case that the traditional themes of research in perception and cognition are devoid of material bearing on issues of blind mobility; indeed, much of the literature cited in earlier sections of this chapter deals primarily with traditional themes and only secondarily or by implication with issues of visual impairment. To some degree, the theoretical underpinnings of mobility in the blind are weak because there has not been a sustained attack on issues related to blind mobility, and there is no self-sufficient theory of blind mobility. In the long run, the theoretical foundation for blind mobility will be stronger for its roots in the traditions of perceptual and cognitive psychology. In the meantime, there is a need to develop sustained research attention in several areas of direct bearing on blind mobility. We make recommendations in four major areas in which active research should be emphasized beyond current activities and give examples of specific project topics.

In each area, ongoing methodological attention should be devoted whenever possible to two issues. First, the population of blind individuals is extremely heterogeneous, and thus individual differences must be evaluated. Individuals vary on a wide range of characteristics, such as remaining visual function, early visual history, etiology, and additional handicaps, all of which have potential implications for mobility. To have optimal impact on the mobility of blind people, research must be adequately attuned to the variations in mobility skill and its components that are produced by these variables.

Second, while research on the perception and cognition of blind people as well as the sighted has been reasonably good at describing the end product of a perceptual or cognitive process, it has been notably weak at elucidating the nature of the process itself. This is a serious gap. Research designed to evaluate the nature of the perception and understanding of space often requires of its subjects the acquisition of that perception or understanding, and every opportunity should be taken to assess the acquisition process as well as the product. This is generally a difficult research issue from a methodological standpoint, but a grasp of the processes involved in these areas is critical if we hope eventually to intervene in ways that facilitate mobility.

Making Information Available to the Blind Traveler

Current mobility aids are reasonably effective in making available information from the adjoining space (e.g., shoreline information) and from the path ahead. The travel surface and the extended space pose more difficult problems.

The long cane, when properly used, provides good information about the surface ahead, but it does so only for a relatively short extent (about 1 m). No aid that is currently available extends this range

effectively, although the Lasercane does provide drop-off information. The blind traveler needs more preview of the surface than this: how much more is not clear but certainly depends on such variables as walking speed and the variability of the terrain itself.

RECOMMENDATION: Research should be addressed to the nature of the information a blind traveler needs to preview the travel surface and to the corresponding question of the best manner of presenting such information to the traveler.

The sighted traveler typically (although not always) has perceptual information available about a far more extended region than does the blind traveler, such as from landmarks that are visible from considerable distances. Such information is most obviously useful when alternative routes must be taken (for example because of an obstruction in the path), but it also serves to lessen the cognitive load for sighted travelers--they can forget temporarily where they are and can usually reestablish their positions in the space quickly and easily. The blind traveler is at a serious disadvantage by not having such information available. It should be an extremely high priority to explore ways of overcoming this disadvantage.

RECOMMENDATION: In research on ways to assist blind travelers establish their positions in space quickly and easily, two approaches should be used: (1) the use of fixed information sources in the environment, such as beacons to enable the establishment of position (such as the VOR system for aircraft) and (2) the training of larger-scale geographic orientation capabilities in the blind traveler him- or herself.

Forms of Information Display

In what form might these kinds of information most effectively be presented? Information from the environment may be presented in many forms, and it is not obvious which forms are more or less effective. There are several critical questions in need of answers from research:

Is the use of a natural cue correspondence, such as auditory IAD for azimuth direction in the Sonicguide, superior to a more arbitrary matching of dimensions, such as signal rate for distance in the Mowat Sensor (see Chapter 6)? Although the use of natural matches seems intuitively desirable, some evidence (e.g., Strelow and Warren, 1985) suggests that this may be an area in which intuition is not an effective guide. In any case, the issue is amenable to empirical investigation, and it is a very important question.

To what extent is preprocessing of information desirable? One approach, as exemplified by the Sonicguide, is to present a relatively complex signal that is not artificially simplified for the user. The other extreme is to have the device abstract from a complex array of stimulation a few pieces of salient information to be delivered to the user in highly simplified form, as in the computer vision system

described by Deering (1985). Some very fundamental questions of human information processing capabilities and perceptual-cognitive function are involved here, and the effective design of future mobility aids will depend more on empirically generated answers than on simple conviction that one approach or the other is best.

Is redundancy of information useful and desirable, and if so to what extent? The sighted observer often has several sources of perceptual information available, for example, about the distance of objects (stereopsis, convergence, interposition). Is the introduction of such functional redundancy desirable for the blind? The desirability of backup information must be weighed against the demands for increased information processing that a device designed to provide it would impose. While clearly a pragmatic issue of mobility aid design, this issue is also of interest to theories of human information processing and performance, quite aside from the question of mobility.

RECOMMENDATION: More research should be carried out on the relationship of natural cue to human processing capabilities, on the desirability of the information preprocessed by travel aids, and on the usefulness of information redundancy in the use of travel aids.

The Relationship Between Perceptual and Cognitive Information

Although a sharp distinction between perceptual and cognitive levels is impossible and probably not desirable to draw, there is a significant area of interaction that must be explored with respect to blind mobility. Blind travelers acquire some immediate perceptual information about the environment and their positions in it, but generally they must also make use of stored information about that environment (or about environments in general) to engage in effective mobility. The referencing of current position and orientation to some stored representation of the environment is critical for effective mobility as long as the travel demands exceed the limits of dead reckoning. That is, travelers must reference currently obtained perceptual-motor information to a stored representation in order to monitor their current activities in relation to the space in which they stand. The means by which this reference updating is accomplished is not well understood.

RECOMMENDATION: It is critical to understand better how blind travelers reference and update information about their position and orientation in space, and we recommend that more research be directed to that issue.

Perceptual Learning Principles

It is unlikely that a mobility aid can be designed that is so spontaneously useful that no learning process is involved in using it effectively. Instead, a perceptual-learning process must be involved that has at least the following aspects:

- (a) Understanding of the variables of the physical world that the mobility aid is designed to convey,
- (b) Discrimination of the variables of stimulation presented by the mobility aid,
- (c) Learning the correspondence between the physical world variables (a) and the aid-presented variables (b).

All this must be accomplished in the context of a stimulus environment that goes beyond the user-device interface: natural stimuli also occur that may facilitate performance if they can be effectively attended and processed, and, perhaps just as important, other perceptual-cognitive-motor tasks must be carried on simultaneously that are vital but that have no immediate relevance for the task of mobility.

RECOMMENDATION: Research should be fostered on the perceptual-motor learning processes that underlie the use of mobility aids.

SENSORY ENHANCEMENT AND SUBSTITUTION

Blind people must depend on nonvisual senses for information to help them locate and identify objects and persons, to guide the development of their personal relations, to regulate their motor behavior in space, and to provide an overall conceptual organization of their spatial environments. Determining the role, or roles, of other senses in compensating for the loss of visual information should become a major focus of scientific inquiry. There is an urgent need to determine how and to what extent sensory substitution or enhancement techniques can best be used to prevent or compensate for deficiencies in spatial motor behaviors in persons with visual impairments.

Mobility involves more than just a resolution of the problem of getting from here to there. Many kinds of sensory information have to be dealt with in both the immediate or near environment and the more remote environment, and, in both environments, there is information that requires high resolution. In the immediate environment, within touch by the body or with a cane, not much resolution is required to determine if a person is present or if a chair is occupied; it requires more resolution, however, to read the numbers on a hotel room door or to know a person's identity. The same is true of the more remote environment. It does not require much resolution to know that a building is present or that one is near a street with traffic present, but to know the name of a building or a street, and whether it is safe to cross the street, requires higher resolution of the sensory information. Both environments require appropriate orientation to the stimuli present in them and certain mobility skills in order to move about.

The visual system is capable of resolving information in both the immediate and remote environments, but this is not always true for the other sensory systems, such as the auditory, somatosensory, and kinesthetic systems. Use of these other modalities requires that a person pay more careful attention to the spatial stimuli present in the environment and the use of sensory aids, especially for information requiring high resolution. Although learning is necessary to use spatial information acquired through any sensory modality, there are special problems in the absence of visual information or with the use of sensory aids. The information needed to locate something in the environment may be quite different from the information needed to

identify it. The problems posed by sensory enhancement are different from the problems posed by sensory substitution, as are the problems posed by age and by type of visual impairment.

THE VISUAL SYSTEM

What are the visual requirements of mobility? We consider separately visual information gathered from immediate and more remote environments.

The Immediate Environment

By immediate environment, we mean information within a stride or two (perhaps the space defined by the extension of the long cane). Of primary concern within the immediate environment is obstacle avoidance. Experimental data exist concerning the visual requirements of obstacle avoidance. Pelli and Serio (1984), at the Institute for Sensory Research, Syracuse University, have studied how visual restrictions of several types limit the ability of subjects to traverse a maze constructed of three-dimensional obstacles. They have found that the visual requirements of this task are very low, that is, substantial restrictions can be tolerated before performance is affected--fields down to 10 degrees, contrast reduction by more than a factor of 10, and spatial-frequency bandwidth of less than 1 cycle per degree. These findings indicate that very little spatial information is required for obstacle avoidance and that most people with low vision will be able to perform this task. Marron and Bailey (1982) have shown that visual field and contrast sensitivity are better predictors of performance on orientation and mobility tasks than acuity.

Some mobility-related tasks may require acquisition of more detailed information from the immediate environment than is needed just for obstacle avoidance. Examples include identifying objects (distinguishing between a person and a mailbox or a tree and a lamp post or recognizing an acquaintance in the hallway). In the extreme, the immediate environment may contain high-resolution information, such as signs or the labels on soup cans. Some laboratory data exist on the visual requirements of these tasks--field, spatial-frequency and magnification requirements for reading (Legge et al., 1985) and face recognition (Iniui and Kensaku, 1984). However, such data have not been collected in the context of mobility, in which coordination of low- and high-resolution tasks may impose added burdens, as described below.

Remote Environments

Vision is used to gather information about objects and spatial arrangement at distances remote from the individual, that is, beyond the reach of the long cane. Work by Gibson (1979) and more recently by Marr (1982) and colleagues suggests that information of this sort relies on

a variety of visual cues, such as motion parallax, stereopsis, shading, texture gradients, and optic flow patterns. Psychology has not yet revealed in detail the circumstances in which these cues are used. Moreover, we have only an elemental understanding of the physiological mechanisms used for processing such information. We do not know how visual impairments of different types and degrees affect the ability to gather such information. Experimental psychologists could contribute to the understanding of mobility by defining the involvement of these cues in mobility tasks and by showing how their use is affected by various visual impairments.

Vision of the remote environment may also be discussed in terms of more global abilities, such as the ability to follow a path from instructions, the ability to reverse a path traveled once, the ability to locate oneself with respect to objects, and the ability to achieve a memorial representation of the environment in which the travel task is performed. We might ask, for example, how severity of field loss or reduction in acuity affects the time needed to master a complex spatial environment.

Information gathered from remote environments may also be discussed in terms of low- and high-resolution tasks. An example of the former is the use of buildings or other large structures as landmarks. An example of a high-resolution demand of urban mobility is the need to read signs at a distance. High-resolution tasks are a major problem in low-vision mobility.

This brings us to the matter of coordinating low- and high-resolution tasks. When individuals with normal vision arrive at unfamiliar street corners, they rapidly locate street signs and traffic lights by first locating them in peripheral vision and then employing saccadic eye movements to bring them to the fovea. Individuals with restricted fields and low acuity have a more difficult job. Although there may be sufficient residual vision to follow the crosswalk across the street, finding and reading the sign is another matter. Typically, pedestrians who have low vision are obliged to use telescopes with small fields. Even if it is successful, the scanning required to find the sign is time-consuming, inconvenient, and, although magnification may be adequate for reading, the demand for scanning and search substantially impedes mobility. More accessible street signs and traffic signals would help. In this connection, talking signs have been explored. Other high-technology navigational aids might also be explored.

It is important to recall that low vision cannot be characterized simply as a loss in acuity. For example, in the case of reading, we know that the presence or absence of central vision is a better predictor of maximum reading speed than is acuity (Legge et al., 1985). With regard to the different component tasks of mobility, researchers will have to determine the significance of subject variables like acuity, field, and contrast sensitivity.

Sensory Enhancement

Sensory enhancement refers to artificial manipulation of patterns of sensory stimulation to make them more useful. The classic form of sensory enhancement in low vision is magnification, which acts to replace small retinal images with larger ones. This reduces the resolving demands of the task. There are other examples of the manipulation of visual stimulation to enhance its value for people with low vision. For example, reversed telescopes can compress a large visual field into a smaller one (minification). In some instances of severe field restriction, this may have benefits for mobility. Careful analysis of the value of such devices for mobility is in order. Other examples of sensory enhancement within the visual domain include the use of image intensifiers for people with night blindness or contrast enhancement hardware in closed-circuit TV magnifiers. The use of Corning CPF color filters for mobility is an intriguing but not yet well-understood form of sensory enhancement. In these examples, some properties of patterns of visual stimulation are transformed, while other properties are invariant. It would be valuable to explore other forms of sensory transformation.

In recent years, engineers and computer scientists have devoted substantial effort to the development of digital techniques for image enhancement and image restoration. Most of these techniques have not been explicitly motivated by consideration of the sensory capacities of the observer. However, it seems likely that image enhancement methods could be tailored to optimize the residual capacity of observers with low vision. Some preliminary work in this direction has been undertaken by Eli Pelli and colleagues at the Retina Foundation in Boston (Pelli and Pelli, 1984). It is an open question as to how such techniques could be implemented to aid mobility.

Finally, characterization of visual capacity is dominated by three variables--field, spatial resolution (acuity), and contrast sensitivity. It would be helpful to give an initial characterization of vision substitution systems using the same variables. For example, we might ask about the field in degrees, spatial resolution in cycles per degree, and modulation sensitivity of a prospective tactile imaging array. The use of common measurement metrics would help in the comparative evaluation of vision substitution systems.

THE AUDITORY SYSTEM

With regard to the auditory system's ability to resolve signals containing distance information, it has an enormous dynamic range (100 trillion to one) and distance information coded primarily through intensity. Accordingly, the distinction between immediate space and remote space is of relatively little importance. The near field flows smoothly into open space with a surprising continuity, except for the tendency of high-frequency components to be more susceptible to air transmission loss, and this susceptibility provides an additional timbre cue in distance estimation.

Given constant loudness of a sound source, sensory resolution in terms of localization and identification remains relatively constant. Median plane localization of sound sources is achieved through the use of binaural time and intensity differences. The human auditory system is capable of detecting binaural time of arrival differences as short as 30 microseconds and binaural intensity differences in the single dB range. The pinna also has an effect on the localization of sound sources in space. The accuracy of localization is determined by the spectral composition of the sound source with pure tones of 3,000 Hz being the most difficult and noise bursts with rapid onset being most effective.

Because most objects do not emit sounds, two other acoustic mechanisms come into play. The first involves passive interaction with sound stimuli emitted from another independent source. These ambient sounds are attenuated, in part because of a reduction in the high frequency components of the complex wave due to the inability of the sound to bend around the object, and in part because of resonances caused by the positioning of the object and the recipient's ear. The second mechanism involves active emission of acoustic signals by the observer and the subsequent detection of the echo reflected by the object. The time delay between the production of the sound and the detection of the echo reveals information primarily about the distance of the object, but also about its position and its textural characteristics.

In both of these cases, the auditory system must be regarded as functioning in a low-resolution mode. The median plane localization of an active sound source is rarely more accurate than 5 degrees. The passive mechanisms are even cruder, providing the observer with little more than presence and minimal position and distance indices.

The ability of the auditory system to identify and interpret sounds, however, is the result of a very high capacity for resolving acoustic signals. Variations in pitch, intensity, and timbre and temporal variation in all three can be discriminated to a fine degree. All of these parameters give natural sounds distinctive signatures and can be easily manipulated in an electro-acoustic system, and this ability provides tempting options for environmental coding. The intrinsic utility of the uncompromised auditory system to gain information about the environment is a very important consideration.

THE SOMATOSENSORY SYSTEM

The somatosensory system is a complex system that provides a wide range of information about the near environment and mediates the perception of motion. In the natural mode (without artificial stimulation), the sensory information may be categorized as a series of progressively more complex functions classified roughly as: thermal sensitivity, sensitivity to pressure and vibration, perception of texture and form, and stereognosis. Appropriate sensory prostheses might use any one or a combination of these somatosensory capacities.

Each of these categories had been studied fairly extensively in relation to the hand and fingers, but much less is known about these sensory capacities in other areas of the body.

Pressure

In the hand, the sense of pressure depends on activity in slowly adapting (Merkel) afferents (Mountcastle et al., 1966). The relationship between skin indentation and subjective magnitude is linear, as is the relationship between indentation and impulse rate in the slowly adapting afferents. Subjectively, one is more sensitive to edges than to flat surfaces. Coincidentally, the slowly adapting afferents are much more sensitive to edges than to flat surfaces (Phillips and Johnson, 1981).

Vibration

Cutaneous vibration evokes a sensation that depends on neural activity in the QA (cutaneous quickly adapting or Neissner) afferents and/or the PC (Pacinian) afferents. At low frequencies, less than 40-50 Hz, the QA's dominate. At higher frequencies, the PC's dominate. Subjective intensity is a monotonic function of vibratory intensity, as are the impulse rates in the QA and PC populations (Mountcastle et al., 1972).

Tactile Form Perception

Tactile form perception is most highly developed at the fingertips, where the limit of resolution is approximately 0.8 mm (Johnson, 1983). This value is based on studies using gap detection, mechanical gratings, and embossed letters as stimuli. This resolution appears to be based on neural activity transmitted via slow adapting (SA) afferents and for complex patterns, like letters, it is not greatly different whether the spatial stimuli are applied to the finger in a stationary manner or the fingers are swept across the stimuli. It is also an interesting fact that the relationship between resolution and the primary afferents is the same in the skin and in the foveal region of the retina.

Spatiotemporal integration involving the fingertips occurs as the fingers are moved across a stimulus or, conversely, a stimulus is moved across the fingers. This integration compensates in some ways for the limited spatial field of the fingertips.

All the proven methods of high information transfer through the skin (Braille, the Optacon, and the Tadoma method) employ the finger pads. That is not to say that other skin areas could not serve equally well, but there is no concrete evidence that they can.

Texture

Tactual perception of texture, which provides information about a wide range of surfaces, is not understood at either a psychophysical or neurophysiological level (Johnson, 1983). The sense of surface roughness, which is one facet of texture perception, is understood to some extent. Subjective roughness magnitude is a nonmonotonic function of surface spatial frequency. At the neural level it appears to be mediated by variation in the impulse rate of SA afferents (Fasman et al., 1985).

Stereognosis

Stereognosis is the appreciation of a three-dimensional form through manual exploration. Recognition of a door handle or of a larger object, such as a chair, are familiar examples. Stereognosis is a complex function of joint angle sensation, which appears to be mediated largely by muscle spindle afferents, tactile form perception, and vibration. Beyond these simple observations, relatively little is known about the physiological mechanisms of stereognosis. However, stereognosis is extremely important and lies at the heart of the success of the cane.

Implications for Sensory Aids

How might the somesthetic sense serve the purposes of a sensory aid? We consider this question within the near field/far field, low resolution/high resolution framework that we have adopted.

All the available evidence suggests that the appropriate sites for the delivery of high-resolution information about the environment are on the hands and fingers. The ideal device would be something like the Optacon; that is, a portable device with a dynamic, two-dimensional display. The user might carry it like a shoulder bag, slipping a hand into the device when he or she wants high-resolution information. Such a device might be used for orientation with a wide-angle view and then zoomed to a specific object, e.g., a sign. When the user is seated, it might be used to examine detailed materials of various kinds, although the most important use may not be text reading; within the near future, that function will probably be accomplished most effectively by character recognition and speech synthesis hardware. The dynamic display may serve most effectively to find and bring the appropriate text into the view of these pattern recognition mechanisms.

The main problem in this area is the lack of appropriate instruments for displaying spatiotemporal information to the skin. It seems clear that the appropriate mode of presentation is the projection of isomorphic spatial patterns onto the skin. It is also clear from everyday experience that the tactile sense of the hands and fingers provides rich imagery concerning texture, form, remote vibration, etc. The ability to read Braille (Foulke, 1982a) and recognize speech by the Tadoma method (Snyder et al., 1982) are two examples that provide some

quantitative indication of this capability. However, we cannot specify with any certainty the form that the dynamic display should take. What is needed is a research instrument that meets or exceeds the capacities of the tactile system. The only instrument currently available for studying the efficacy of dynamic, two-dimensional displays is the Optacon, which falls far short of the physiological capacity of the system. Its pin spacing is 3 times greater than the resolution limit of the fingers, and its stimulus mode is poorly matched to the underlying receptor mechanism. For example, at 230 Hz, the frequency at which the individual pins vibrate, the receptor system with the highest spatial resolution, the SA population, is not even activated. Subjects report that the sensations evoked are unnatural and poorly differentiated. Most find it very difficult to use. The spatiotemporal sensations are not robust and highly differentiated, like normal tactile sensation.

What is needed is a device that spans the full intensive, temporal and spatial range of the tactile system. Investigations with such a device would provide a basis for determining the specifications of working devices and display methods.

It seems unlikely that skin areas other than the hand and fingers will be suitable for acquiring information of the sort that demands high resolution. However, these skin areas might provide an effective portal for low-resolution information.

EXISTING ENVIRONMENTAL SENSORS

A variety of sensory aids for visually impaired people have been developed as technology has advanced, which are discussed in Chapter 6. Here we concentrate on aids that have been termed "environmental sensors." An environmental sensor should be more than an obstacle detector: it should convey the full dynamic character of visual information. We concentrate on this class of aids because, to the extent that they are designed to incorporate imminent advances in electronics and optics, they are more likely to take advantage of the capacities of nonvisual systems.

Sonar Substitution

The first kind of environmental sensor to be considered is the sonar sensory aid. In aids of this type, a small transmitter irradiates the field of view with acoustic waves of very high frequency that encounter objects in space. The reflected waves that are returned to the observer (echoes) are detected and made audible by suitable transducers. This display contains information about the directions, distances, and surface textures of objects in the field of view. The latest advance in this technology has been developed by Leslie Kay of New Zealand (Kay, 1982; Easton and Jackson, 1983). Kay's Trisensor is a modified version of his earlier Binaural Sensory Aid (BSA). As in the BSA, the Trisensor is fitted with widely angled receivers that

sense reflected energy. Energy reflected from an object to either side of the midline results in a transduced signal with an interaural difference in amplitude that serves as a cue for the location of the object. In addition, the Trisensor is fitted with a transmitter that emits a very narrow beam of ultrasonic energy that is returned by reflection and results in a signal that, because it does not exhibit an interaural difference in amplitude, is a monaural signal. The signal provides the user with more precise information regarding the size and location of objects directly ahead. In addition to indicating object direction, both the BSA and the Trisensor code object distance in terms of the pitch of the acoustic display, while surface texture is signaled by the timbre of the auditory signal. It should also be noted that these aids also have adjustable range controls that create "windows" of optimal localization from about 0.3 m up to 5 m.

Recent research has centered increasingly on the psychophysical characteristics and the usability by humans of both the BSA and the Trisensor (Warren and Strelow, 1984a; Easton, 1985). When blind children or adults working under blindfold use the aids to locate small cylindrical objects in near space (within arm's reach), the error of estimation in judging the direction to a detected object is about 5 degrees, as opposed to approximately 1 degree in judging the direction to the source of a natural sound. However, the error of estimation in judging the distance to a detected object is about 5 cm, which is substantially smaller than the error of estimation in judging the distance to the source of a natural sound. This level of performance is typically achieved after 3-4 hours of training sessions. When the space observed by means of the Trisensor is expanded enough to allow sensed objects to be as far as 5 meters from the observer, the error of estimation in judging the direction of an object is approximately 6 degrees, and the error of estimation in judging the distance to an object is approximately 0.3 meters in magnitude. One effect of using the Trisensor appears to be a reduction over previous devices in the magnitude of directional errors, and it is reasonable to attribute such an effect to an increase in angular resolving power brought about by the incorporation of a center channel. However, so far there has been no direct psychophysical comparison of the Trisensor and the Binaural Sensory Aid.

The next logical step in evaluating these aids is a comparison of their usefulness in forming memorial representations of the spatial layout of objects. Both the ability of blind pedestrians to move through object-filled spaces and their ability to update their changing spatial positions and relationships to objects in space need further study.

Tactile Substitution

Bach-y-Rita and colleagues (Bach-y-Rita, 1972; Bach-y-Rita et al., 1969) have developed a Tactile-Vision Sensory Substitution System (TVSS). Early research in the field entailed presenting television camera images directly on the skin, on a point-by-point basis using

tactile arrays worn on the abdomen. The results obtained with the TVSS suggested that such systems can have educational value if the shapes of objects are kept simple and the background against which they are observed is carefully controlled. When the subjects were moving while they observed complex, dynamic scenes, they found the TVSS display very difficult to interpret. In addition, the original TVSS proved to be a relatively cumbersome, uncomfortable system to wear and use while moving about.

Recently, Bach-y-Rita and Hughes (1985) have developed a more reliable and portable TVSS by modifying the Optacon, a device originally intended for use as a reading aid. The modified Optacon presents vibrotactile stimulation to the user's fingertip via the transduction of optical images of distal objects picked up by an array of photosensitive elements in a camera (an optician scanner fitted with a suitable focal-length lens) under the direct motor control of the user (mounted on a headband). The main advantages of the modified Optacon is that it uses reliable engineered hardware (the Optacon), which is readily available to most schools and institutes for blind persons.

The feasibility of this approach rests on the as yet unproven assumption that the skin is functionally similar to the retina in its capacity to mediate information. Like the retina, the skin can sense variation in two spatial dimensions and is capable of temporal integration. Thus there is generally no need for complex topological transformation or for temporal coding, although temporal display factors are being explored with the goal of transmitting spatial information across the skin more quickly than is possible with present systems.

Psychophysical experiments are presently being conducted in order to determine the sensory capacity of the skin with respect to the variables represented in the Optacon display.

RECOMMENDATIONS

On the basis of our findings, we make the following recommendations regarding physiological considerations in sensory enhancement and substitution.

The Somatosensory System

If sensory aids are to take full advantage of the capacities of the somatosensory system, they must effectively engage the mechanisms responsible for tactile perception and stereognosis. Natural examples of tactile perception are Braille reading and texture perception.

The necessary condition for tactile perception is cutaneous deformation. There is, in principle, no reason why a device cannot simulate the deformation patterns encountered in normal tactile experience and recreate any tactile sensation of which the system is capable. However, no currently available device comes close to

achieving this objective. Such a device should have a dense array of probes with a spacing of 0.8 mm or less. Individual probes should have a dynamic range of a least 2 mm and a frequency range from 0-300 Hz. Another form of an optic device might consist of a modifiable bas relief display with protrusions of nonvibratory pins proportional to the gray level. The image received by the fingertips would consist of a TV frame, updated at will by the blind subject scanning the image with the fingertips of one hand. Once such a device is developed, the question of appropriate methods of stimulation can be pursued.

RECOMMENDATION: To speed up progress in mobility research, high priority should be placed on the design and development of a device that can simulate the tactile perception that results from cutaneous deformation.

Since the devices currently available for stimulating skin are so much more limited than the sensory system they address, research tends to illustrate the limitations of the device rather than the sensory system. To take a specific example, using the Optacon as a research instrument is analogous to doing auditory research over the telephone. The device has limited utility as a research instrument.

Stereognosis depends on the patterns of neural impulses that are generated when, as a consequence of the movement of parts of the body, the receptors in muscles, tendons, and joints and the receptors in the skin are excited. It is stereognosis that largely accounts for the success of the long cane as a mobility aid. The cane works because it is effectively coupled to the stereognostic system. A hypothetical example of the kind of device that we have in mind is an electronic cane operating on some reflectance principle (e.g., sonar or radar) with an adjustable range. The electronic cane, which might be held in the hand like a flashlight, could offer its user a menu of functions. In one mode, it might simulate a rigid cane of fixed length and present to the hand of its user the same pattern of stimulation that would be presented by a real cane, like the jolting sensation that occurs when a cane comes in contact with an object. In another mode, it might function as a directional range finder and be used to detect obstacles or openings such as doorways.

RECOMMENDATION: High priority should be given to the development of mobility aids that engage stereognosis.

The Auditory System

As in the case of the TVSS, the performance enabled by existing devices that substitute auditory stimulation for visual stimulation should be assessed more thoroughly and carefully than it has been to date. Closer interaction between engineers and psychologists with specialization in human factors engineering would facilitate this endeavor. A more thorough assessment of existing sensory aids is needed, but there are more fundamental issues that must be addressed.

RECOMMENDATION: We recommend that basic research be fostered concerning the cues on which the auditory perception of distance depends as well as research to develop transduction schemes that yield acoustic displays whose cues to the perception of space are analogous to the cues in natural acoustic displays.

Mobility and Low Vision

We need research that will make possible a better definition of the relative importance of the several cues available for the perception of depth, and how their use is limited by different forms of visual impairment. The effect of visual impairment on spatial learning also merits study. When the natural optical display from which visual observers acquire spatial information is transduced to create an acoustical display, extensive recoding takes place. Only one cue, the directional cue provided by interaural differences in amplitude, is the same in the transduced display and the natural acoustic display from which auditory observers acquire information about space. The cue to distance provided by differences in pitch, and the cue to surface texture provided by differences in timbre, are arbitrary. What is important to recognize is that a transduced display more closely analogous to the natural acoustic display should be interpretable with significantly greater speed and accuracy than the transduced displays of existing devices. Of course, the auditory perception of space, in many respects, is not well understood. For example, the cues for auditory ranging are apparently provided by complex variation in the amplitudes of several simultaneously occurring signals. The cues provided by variations in the amplitude of a single signal would be ambiguous. However, basic research concerning the cues on which auditory ranging depends will be needed before such information can be taken into account in the development of a transduced acoustical display that is analogous to the natural acoustical display.

RECOMMENDATION: A careful experimental analysis is required to identify the components of the mobility task. Once this is done, further research should be carried out to clarify the demands on vision made by each of these components.

Performing tasks that require changing from one level of resolution to another, such as the task of first finding a street sign and then reading it, poses a serious problem for pedestrians who depend on mobility aids for the information they need to travel, and it may be that current or imminent technology can offer a solution to this problem. There are some possibilities for visual enhancement that depend on techniques and instruments currently available or that could be made available with little additional development. For instance, tunnel vision might be enhanced by reversed telescopes or Corning CPF filters, and digital image enhancement could be used to create displays that compensate for various visual deficiencies. Finally, it is generally agreed that visual capacity is adequately defined by the

measured values of three variables: spatial resolution, contrast sensitivity, and extent of the visual field. The visual capacity enabled by a mobility aid could be defined in the same way.

RECOMMENDATION: Research should be conducted to determine the feasibility of defining the sensory capacity enabled by the use of a sensory substitution system, such as a VTSS, in terms of the three variables that define the capacity of the visual system. For example, at the appropriate point in the development of a new VTSS designed to display a tactile analogue of a visual image, its field of view, spatial resolution, and contrast sensitivity could be measured. The measured values thus obtained should give a fairly accurate indication of expected performance. This approach would be useful, not only to evaluate individual substitution systems, but also to compare different substitution systems.

Detrimental Effects of Mobility Aids

The designer of a sensory substitution system should be mindful of the natural ability of the sensory system to be addressed and the interference that may be caused by substitute signals. For instance, the auditory system has useful ability to acquire spatial information from the natural acoustic display, and the benefits associated with the use of a sensory substitution system must be weighed against the costs incurred by compromising natural auditory ability.

A sensory aid with the intended function of enhancement may also interfere with reception of the natural acoustical display. For instance, in an effort to improve the signal-to-noise ratio in the region of the audible spectrum in which speech signals occur, a hearing aid may be designed to filter out both the low frequencies, on which the detection of resonances depends, and the high frequencies, on which the detection of sound shadows and distance cues depends. Automatic volume level controls, commonly used in modern hearing aids, eliminate distance cues provided by differences in loudness. A hearing aid with these features might seriously interfere with the ability of a pedestrian who is both visually and hearing impaired to acquire spatial information.

RECOMMENDATION: An effort should be made to develop a hearing aid that is effective with regard to the reception of speech, but not at the expense of effectiveness with spatial information.

Animal Models

Sensory substitution experiments with animals, such as primates, may be the only practical way to acquire an understanding of the potential benefits and limitations of the devices currently available or in the planning stage. Sensory substitution experiments using animals provide the only means available to use for evaluating the

possibility of negative effects on neurophysiological development as a consequence of early and long-term use of sensory aids, and such experiments should be conducted before the effects of their long-term use by blind human infants are assessed.

Observations of behavioral changes that correlate with changes in functional activity patterns of the central nervous system (Bach-y-Rita, 1972) should prove useful in identifying characteristics of device input that prove to be detrimental to the individual user, so that such characteristics can be altered or eliminated. Beneficial characteristics could also be identified and enhanced. Sensory substitution devices may have to be tailored to meet the needs of the individual, much as other prostheses are, and just as prescribed medicines are.

At the present time, we can only speculate about the physiological basis of effective sensory substitution, because the data available will not allow us to do otherwise. However, we can make and test some rudimentary hypotheses, most of which involve plastic properties of the central nervous system. In essence, when we ask questions about the basis of sensory substitution, we are also asking questions about the nature of processes that depend on the plasticity and compensation properties of the central nervous system. The possibility of being able to control modifications or organizational processes in order to enhance compensation in the advent of a sensory deficit presents a significant challenge to science and technology.

RECOMMENDATION: Research should be encouraged on the use of animal models to study the effects of device use on sensory development and functioning and to assess the relative contributions of the various kinds of information provided by sensory aids to the development of spatial knowledge and spatial ability.

Chapter 6

THE TECHNOLOGY OF ELECTRONIC TRAVEL AIDS

On the basis of some assumptions regarding the types of environmental information needed to enhance independent travel by visually impaired people, this chapter provides a review of mobility aid technology to date. We discuss strengths and weaknesses in the information acquisition and display of these devices, and we make suggestions for research aimed at improving on past aids, along with speculation regarding existing and future technology that could be applied to the problem.

INFORMATION NEEDS OF THE PEDESTRIAN

As previous chapters have discussed, it is generally accepted that, in order to engage in safe and efficient travel, the pedestrian must have access to certain categories of environmental information. Suggestions regarding the information needed have been put forward by Foulke (1971), Kay (1974), Strelow (1985), and others and usually include the following concepts:

(1) Information is needed regarding the presence, location, and preferably the nature of obstacles immediately ahead of the traveler, from ground level to head height and over a wide enough area horizontally to cover the width of the traveler's body. The minimum distance or range over which this information is needed is a comfortable stopping distance at normal walking speed. A greater range is desirable.

(2) Information regarding the path or surface on which the traveler is walking is highly desirable; this includes texture, gradient, and upcoming steps (both up and down) and boundaries to left and right (including step-downs at sidewalk edges).

(3) Information regarding the position and nature of objects to the sides of the travel path is desirable. This includes hedges, fences, doorways, trees, etc., forming part of the shoreline on either side of the path.

(4) Other information to enable the traveler to maintain a straight course is extremely helpful, notably the presence of some type of aiming point in the distance, often provided in practice by distant traffic

sounds. Knowledge of absolute or relative direction of travel is also helpful.

(5) Information on landmark location and identification is needed. This can include information under the above categories (especially 3) and also includes the ability to positively identify specific environmental features such as building entrances, room numbers, elevators, rest rooms, floor numbers, intersections, etc.

(6) Sufficient information must be provided by one means or another to allow the traveler to build up a mental map, image, or schema for the chosen route to be followed, including turns and other discontinuities.

PAST AND PRESENT MOBILITY AIDS

With the above assumptions in mind, we examine the progress to date in technology designed to acquire and display at least some of the above types of information.

The Long Cane

The long cane, introduced in its present form by Richard Hoover (1950) in the late 1940s, effectively allows detection of obstacles within a 3-foot range and tends to warn other pedestrians to get out of the way. The former feature requires fast stopping reaction or slower walking speed when an obstacle is encountered, while the latter does not add to the grace of independent travel. The skilled user of a cane can, however, acquire directly most of the information needed regarding obstacles and path or surface. In addition, location cues from the sounds emitted when the cane tip (especially a metallic tip) contacts the ground can provide a surprising amount of the additional information regarding objects at the sides of the path. These subtle cues are frequently unknown to, or underrated by, the sighted community (except for mobility specialists) and their presence provides a powerful incentive for skilled blind pedestrians to eschew electronic travel aids. These subtle cues and their use receive a great deal of attention in orientation and mobility training.

Electronic Travel Aids

Following the development of radar and sonar technologies for remote sensing during World War II and the introduction of transistor technology, which made portable electronic devices practical, inventors began to see the potential for various obstacle-detection devices to aid blind people. A huge number of such devices were developed, mostly using the transmission of an energy wave (usually ultrasonic) and the reception of echoes from objects in or near the traveler's path. The choice of ultrasound for the transmission medium, as opposed to light or radio waves, was dictated by the convenience with which echo ranging

could be performed in this medium due to the relatively slow speed of propagation. Optical sensing was used in some cases, when the operation of the system was passive or when range measurement was not a design goal (e.g. in the Laser Cane).

Sonar technology, as it existed by 1960, was well developed for underwater purposes, but its use above water was complicated by much-increased signal attenuation and the difficulty of coupling a transducer effectively to the air. These problems were overcome, and ultrasound became the most popular sensing medium for mobility aids. The main limitations of the technology were limited useful range and difficulties experienced with reflections from smooth surfaces (which act like mirrors to ultrasound due to its long wavelength).

Clear-Path Indicators Versus Environmental Sensors

Once the technical problems had been solved, the principal arguments among developers revolved around the amount and type of information that is desirable to present to the user and the manner in which it should be presented. Development followed two schools of thought. One class of aids, known as obstacle detectors or clear-path indicators (Foulke, 1971), warned only of the presence and sometimes the approximate range of obstacles directly in the travel path, while generally not being concerned with identification of the obstacles detected. Such devices generally had the advantage of relatively lower cost.

Included in this category is the Russell Pathsounder (Russell 1965), which uses a 30-degree ultrasonic beam transmitted from a chest-level unit suspended from the user's neck. It can provide tactile and auditory warning of objects up to 6 feet ahead and allows some range estimation. The Mowat Sensor (Pressey 1977) is a hand-held, pulsed sonar system with tactile output. The narrow-beam, flashlight-sized device vibrates with a period proportional to target range. The Nottingham Obstacle Detector (Armstrong 1973) is similar in operation and shape to the Mowat Sensor, except that it provides an auditory readout of range with eight notes corresponding to the musical scale. The Laser Cane (Nye, 1973) is a conventionally shaped long cane with laser emitters and receivers aimed to detect overhangs, down curbs, and targets straight ahead within a selectable range of 6 to 12 feet, giving auditory and tactile warnings.

A second category of aids, known as environmental sensors (Foulke, 1971) attempts more than mere detection of obstacles. The first of these to be developed--and one of the most well known--is the Kay Sonic Torch (Kay 1964). One of the few devices designed to replace rather than merely supplement the long cane or dog guide, the Sonic Torch (which is no longer in production) was a hand-held, narrow-beam ultrasonic device with an auditory output presented via an earphone. The Sonic Torch, in contrast to those ultrasonic travel aids of the obstacle-detector class (which normally use simple single-frequency pulse transmission), transmitted a wide-bandwidth (40-80 kHz), frequency-modulated, ultrasonic energy wave. Reflected signals from the Sonic Torch were converted to the audible region by multiplication

with the transmitted signal. The result was an auditory signal extremely rich in information--the pitch corresponding to range and the timbre corresponding to variations in target surface texture, enabling target identification.

Later developments in this concept led to the Binaural Sensory Aid (Kay 1966), known commercially as the Sonicguide. Employing the same methods of transmission and reception as the Sonic Torch, this device looks like a pair of spectacle frames; it is worn on the head with a wide-beam (60-90 degree) transmitter. The two receiving transducers are splayed a few degrees to the left and right, and their signals are presented separately to the left and right ears, giving a built-in direction cue. The Sonicguide is used in conjunction with the long cane or dog guide, like most other electronic mobility aids.

Recent Developments

The first generation of mobility aids, described above, was criticized on grounds that included cost-effectiveness, the masking of natural echo-location cues, and the necessity of training for the more complex aids.

In the late 1970s and early 1980s, device developers came up with some new solutions and refinements to address these problems. Criticism of the degree of information presented by the Kay Binaural Sensory Aid was answered by the development of a prototype single-channel system with a narrow beam width, eliminating the constant signals returned by objects in the periphery, while retaining the advantages of the binaural version for object identification.

To shed light on the controversy regarding the optimal form of range cue for an obstacle detector, the American Foundation for the Blind developed a microprocessor-assisted ultrasonic ranging device (Maure et al., 1979) using the sonar electronics from the Polaroid auto-focusing mechanism. The microprocessor can be programmed to present its output in any one of a variety of auditory codes, including the spoken voice. Other Polaroid-based ranging systems have also been developed (Heyes, 1982). In the Federal Republic of Germany, the Siemens Company produced its own spectacle-worn and hand-held obstacle-detector systems, while in England the developers of the Nottingham Obstacle Detector devised a modified head-worn version, the Sonic Pathfinder (Heyes, 1984), designed to allow discrimination of target direction while remaining basically an obstacle-detection system.

Investigations were made of the feasibility of tactile information presentation in a mobility aid, in order to overcome the criticized masking effects of auditory displays (and also for use by people who are both deaf and blind). Early research in this field at Smith-Kettlewell and elsewhere (Collins, 1967; Collins and Madey, 1974), centered on the direct presentation of television camera images on the skin, on a point-for-point basis using large (32 x 32 or 20 x 20 point) tactile arrays on the abdomen. As discussed in Chapter 5, it was concluded that this concept has educational value when confined to

simple images and shapes, but the complex scenes encountered outdoors cannot be readily interpreted through the skin for use in travel.

Two alternative approaches were then investigated for preprocessing the tactile information, thus simplifying the display. The first approach used a scanning sonar system (Brabyn et al., 1981) to present a plan-type view of the environment on the skin, displaying range and azimuth information in the same manner as a PPI radar display. This approach was successfully tested, but the expense of the large tactile arrays militated against successful commercialization. An alternative approach, using computer processing of video images to extract only the features vital to mobility (such as curbs, poles, fences, etc.), was then tested. Range and direction were coded on a one-dimensional tactile array, and supplemental synthetic speech information was used in the system output (Collins and Deering, 1984).

In order to overcome difficulties experienced with ultrasonic obstacle sensors when attempting to detect smooth surfaces at oblique angles, an infrared ranging system was designed at Smith-Kettlewell. The prototype device uses a disparity technique that does not require complex electronics for propagation delay measurements. The initial version uses an auditory output, with an inverse relationship between pitch and range. The beam is extremely narrow (approximately 5 degrees), and smooth surfaces such as linoleum can be detected at angles up to approximately 60 degrees from the perpendicular.

Orientation Aids

Orientation involves two aspects: (1) area familiarization--becoming acquainted with a geographical area or with routes within it and (2) navigation--finding one's way from location A to location B. Navigation can be accomplished either by keeping track of one's position with respect to prominent landmarks or by following a series of rote directions.

The primary aids used in area familiarization in the past have been the use of a sighted guide or a tactual map. Experience and research have shown tactual maps have met with only limited success in familiarizing blind people with a complex environment, such as a city or college campus. Several electronic aids have recently been developed to assist in both area familiarization and navigation. The "Talking Signs" system (Loughborough, 1979), developed at Smith-Kettlewell, uses a network of low-cost infrared transmitter modules placed on normal navigational signs in the environment, such as street corners, bus stops, corridors, and room and building numbers. A voice output corresponding to the wording of the sign is produced by a hand-held receiver, which receives the infrared transmissions and converts them into a spoken message. Each transmitter contains a computer memory chip on which its message is stored. This system is now in commercial production.

A similar idea is being pursued by the Georgia Institute of Technology in the development of its Sonic Orientation Navigation Aid (SONA) system (Kelly, 1981). This orientation aid uses radio-activated

auditory beacons to accomplish the task. If, for example, a user is searching for an elevator, he or she enters a corresponding numerical code on a key pad mounted on the hand-carried transmitter. The transmitter then interrogates any receivers in the vicinity. If a receiver is present on an elevator nearby, it will accept the code and produce an auditory beep.

Obviously, successful dissemination of such orientation and navigation systems is problematic, due to installation costs. Even though substantial and expensive modifications to the environment have been made for the benefit of wheelchair users, it does not currently appear likely that the same types of changes will be made for the blind population.

Optical Aids for Low Vision

While low vision encompasses a wide range of visual impairment, existing optical orientation and mobility aids may nevertheless be divided into four types: distance magnifiers, minifiers, absorptive filters, and image intensifiers. In many cases an aid is designed to serve more general purposes for the individual than orientation or mobility.

Distance magnifiers (telescopes) (Bailey, 1984) are used for the identification of environmental features such as signs, room numbers, etc., and in orientation to identify hedges, fences, doorways, trees, etc. Considerable skill is required in the use of these aids for the following reasons.

First, the optical leverage of a telescope amplifies small hand tremors into large image translations, making their use suitable only for those with a steady hand (which older people are less likely to have). Second, because the image through a telescope portrays only a small area of the environmental field, it is difficult to aim the device at a desired object. To read a street sign, for example, the user may have to track along the length of the sign pole as an aid to sighting. Third, focusable telescopes are difficult and inefficient to use, especially when the image of best focus is degraded by the very optical and neural impairments that bring about the need for a telescope.

Additional limitations of telescopes are that: (1) considerable light loss lowers the image luminance, reducing visibility of details and overall effective contrast and (2) for fixed focus (to infinity) telescopes, minimum usable range is restricted to greater than 6 meters.

A second class of optical aids for low vision includes image minifiers, such as reversed telescopes. While distance magnifiers expand a small portion of the field to a size that allows identification for those with central field and/or resolution losses, minification aids compress a wide field to a small central region of the retina. They are designed to allow detection and identification of objects on the periphery of the travel path for individuals with field constrictions. Minification aids suffer from the same light loss problems as forward telescopes and have not been well accepted in practice. Users

also find the unnatural optical flow pattern disturbing. The user is inadvertently retraining the vestibular-ocular response with these aids and may find that they produce dizziness and even nausea.

A variant of this technique is the Amorphic Lens by Designs for Vision, which compresses the field only along the horizontal dimension, presumably on the theory that the view along the sides of the observer is more important for mobility than that in the vertical periphery. The Amorphic Lens produces somewhat disturbing distortions of the field, as the relative sizes of objects change with continuous rotation of the head, but it is considerably more graceful to use than spectacle-mounted or hand-held magnifiers or minifiers.

A third class of aids is the absorptive lenses. It includes sunglass and Polaroid filters, which reduce ordinary glare from sunlight and specular reflections, and filters that selectively absorb light from one part of the visible and/or invisible spectrum. Selective filter are used primarily to remove short wavelength light that scatters more easily than long wavelength light and to remove ultraviolet light that with some pathologies can produce fluorescence of the media. Light scatter and fluorescence, of course, degrade the retinal image and reduce overall contrast, and such filters are designed to alleviate such effects. An important trade-off, however, is the problem that reducing the light with filters also reduces effective contrast of the image.

The fourth class of mobility aids for low vision is the image intensifiers, intended especially for those with retinitis pigmentosa. These range from simple devices, such as wide-angle lamps (Morrisette and Goodrich, 1983), which increase illumination and hence effective contrast on and around the travel path, to more sophisticated devices, like the ITT Nightscope (Berson et al., 1973), which displays a video image of the system travel path sensed by a photo multiplier that is more sensitive than the eye. These aids suffer from a lack of grace and are effective only to the extent that the user can see and interpret the information acquired visually.

LIMITATIONS OF EXISTING TECHNOLOGY

As stated at the outset of this report, the functional utility and user acceptance of mobility aids should be considered in the context of the four criteria for successful mobility: safety, comfort, grace, and independence. None of the aids produced to date has achieved broad market penetration. In part this has been due to the resistance of some groups of consumers to use or support the use of electronic mobility aids, and in part to the limitations of the technology itself. There are a number of probable reasons for this phenomenon:

- Information Limitations. It is evident that each of the approaches taken to date by designers of mobility aids is capable of acquisition and display of only a subset of the required mobility information outlined earlier. No device by itself--including optical aids or the long cane--provides all the required or desired information.

- Expense. All commercially available electronic travel aids are relatively expensive, costing between \$300 and \$3,000.
- Relation to the Long Cane. Most are designed to supplement (rather than replace) the long cane or dog guide, and there is disagreement over whether the additional information they provide is worth the very considerable extra cost and the effort of training. A skilled user of the long cane can use the sounds emitted by the metallic cane tip for natural echo-location, providing a surprising amount of information about the immediate environment. This category of user, although not typical of the general population, would require substantial additional input from an electronic aid for its use to become worthwhile.
- Auditory Cues. The auditory displays of many aids may mask the subtle echo-location cues mentioned above as well as important ambient sounds.
- Training Difficulties. For the more complex aids, the training required to master their use generates resistance. This appears to apply to many optical aids as well as electronic ones.
- Conspicuousness. Most aids to date for both blind and partially sighted people are conspicuous (not meeting the criterion of grace), and many are not conveniently removed or deactivated when not needed.
- Limitations of Scale. Those aids developed to date addressing orientation problems would be very expensive to install on a large scale.
- Lack of Performance Measures. There has been little success in demonstrating that optical or electronic aids for blind and partially sighted people actually improve their mobility. This lack of success reflects the crudeness of measures as well as the limitations of the aids themselves.

Although these speculations are offered the reasons for the lack of acceptance of optical and electronic aids for mobility, not all the reasons are well understood--particularly in the area of magnifiers and minifiers for partially sighted people. In summary, the market need appears to be for mobility aid technology that is inexpensive, easy to learn, and not distracting from natural cues. The technology should, however, display significantly more information than what is available from natural cues and be able to give a demonstrable improvement in travel performance.

RECOMMENDATIONS

We can expect further improvements in electronic mobility aids to be limited less by technological considerations than by two other main factors: the determination and definition of the information needed by the traveler and the capacity of the nonvisual senses to process the information via a suitably encoded display. Compared with these problems, the development of technology to acquire and encode the information is relatively straightforward. Solution of the problems,

in turn, will depend on our ability to evaluate mobility performance and real needs for information (Leonard and Carpenter, 1973; Brabyn and Strelow, 1977; Dodds et al., 1983).

On the basis of this review, we make research recommendations in a number of areas.

Problem Definition

Information Needed for Mobility

The critical types of environmental information needed for mobility (and their relative priorities) must be established by experiment, giving a more concrete starting point for the problem of information acquisition and display. A preliminary analysis suggests that this information should include obstacle detection and identification, path surface discontinuities, shoreline information and other "straight course" input, and landmark identification.

RECOMMENDATION: Research should be undertaken to establish the types of environmental information needed to address the problem of information acquisition and display in the development of electronic mobility aids.

Research on User Skills

As a prerequisite for electronic aid design, research is needed to investigate specific aspects of existing user skills, including determination of the prevalence of echo-location skills among the blind population and determination whether such skills would be significantly improved by use of metallic cane tips, improved training methods, or both.

The importance of these subtle echo-location cues needs to be determined, since certain electronic aid displays can mask them. Research is also needed to determine the precise ways in which different low-vision pathologies affect mobility performance.

RECOMMENDATION: Research should be undertaken on the relationship between user skills and electronic travel aid design and display characteristics.

Technology for Display Design and Simulation

RECOMMENDATION: Simulation of information displays should be developed. Different methods of displaying information for mobility must be carefully designed to match the sensory systems and tested by experiment (largely without developing sophisticated hardware). To achieve this, displays can be simulated manually or with simple technology, and their effects on mobility performance can be measured.

Technology for Optical Aids

RECOMMENDATION: Research should be conducted to investigate why existing aids are rejected as well as the conditions required for acceptance. These results will be essential to the design and use of future travel aids.

RECOMMENDATION: The visual requirements for mobility should be explored fully. Visual parameters to be studied include the necessary and sufficient sizes and locations of visual fields and contrast thresholds for mobility and ocular motility, including the ability to scan the environment and track moving objects.

Recommendation: Research is needed to study the kinds of image transformations that will be both useful and acceptable with minimal disturbance to the user:

Research and development of innovative lens systems is needed. The Amorphic Lens, described earlier, might perhaps be improved on by using a nonuniform compression of the periphery that would give priority to the most important areas of the periphery for mobility. Research is also needed to determine how much image compression can be tolerated in a minifier, producing a wider field in which obstacles can be better detected without destroying the usefulness of the central field in identifying objects or tracking an aiming point.

Research is needed to study the application of auto-focusing techniques, such as those found in cameras, to be used in future telescopic aids.

Further research is needed to investigate both the objective assessment of glare and the measurement of image degradation as a function of wavelength composition of the light. These results would facilitate a rational choice of absorptive filters to produce the most effective attenuators of glare with the least amount of overall light loss.

Technology for Information Acquisition

Once the critical information required for mobility has been established in accordance with our recommendation pertaining to the identification of information needed for mobility, a wide variety of technologies should be explored for the acquisition of this information from the environment.

Optical, Opto-electronic, and Other Electromagnetic Sensing Systems

The use of miniaturized solid-state video cameras coupled with miniaturized image processors offers one flexible method for information acquisition. In addition to optical sensing systems, other sensing systems based on electromagnetic phenomena may also be

applicable. These include millimeter radar, infrared and heat sensors, and magnetic sensors. Light amplification systems can also be useful in low vision.

RECOMMENDATION: Researchers applying electromagnetic sensors should be urged to find a way to process and display the information auditorially or tactually in an easily interpretable manner.

Sonic and Ultrasonic Systems

Sound-based sensing systems suitable for information acquisition in this context may include use of both audible and ultrasonic sound waves. Appropriate audible signal transmission and reception may improve echo-location abilities.

RECOMMENDATION: We recommend that research and development programs be initiated to adopt ultrasonic transmission and reception systems for both simple and complex degrees of information acquisition, ranging from simple pulsed transmission and reception to phased array, variable beam width, focused or unfocused scanning systems. Furthermore, we recommend that new developments in ultrasonic technology, currently in research use for spatial sensing by blind children, be carefully evaluated for possible application to mobility.

New developments in wide-band frequency modulated ultrasonic spatial sensors (which have a built-in ability to display, auditorially, a relatively large quantity of information) include greater resolution, adjustable range, automatic level controls, and the simulation of the human retinal response by the provision of a narrow central beam and width (and weaker) peripheral beams that can be switched off or on at will. These new systems should be thoroughly investigated to determine their value in new mobility aids.

Information Acquisition for Orientation and Navigation Aids

Considerable research has already gone into the development of automatic navigation systems for military and civilian applications (e.g., the navigation of cruise missiles, ships, aircraft, and ground vehicles). The two essential components of an automatic navigation system are (1) a digital "map" representation of the geographical region of interest and (2) a functional module that senses the vehicle location via some combination of inertial, satellite, or radar sensors. The two components together might find use as a navigation system for the blind population.

RECOMMENDATION: We recommend that exploration be made of the potential application of digital map and positive sensing systems to navigation and area familiarization for blind or visually impaired people. Information acquisition technologies that could be applicable

include inertial sensors, satellite and radio navigation data, footstep measurement and monitoring devices, and electronic directional devices, including compasses. Improved and less expensive methods of providing environmental labels, such as solar-powered coded transmitters or passive coded reflecting strips, which could be interrogated by intelligent transceivers carried by the pedestrian, should also be investigated.

Technologies for Information Display

Auditory Displays

RECOMMENDATION: For auditory information display, the use of synthesized speech needs to be tested (this can be done by simulation, as mentioned earlier). Brief verbal messages, at a level of complexity selectable by the user (or in response to user interrogation) may provide a means of display for part of the information generated by acquisition systems.

Speech is a very redundant means of communication. Other auditory codes could well be more efficient (but may require more training).

RECOMMENDATION: Efforts should continue to devise nonverbal displays having simple, easily learned underlying auditory codes but from which progressively greater degrees of information can be extracted as experience accumulates (such as that used in the swept-frequency ultrasonic family of devices). Simpler coding systems conveying less information may be useful in conjunction with other natural or artificial sensory inputs.

RECOMMENDATION: Research and development projects are needed to investigate the use of externalized or stereophonic auditory displays. These displays have the potential of providing the user navigational information in real time both for environmental familiarization and for inclusion in new mobility devices. These investigations should study both auditory and synthetic speech displays. The goal of the research and development effort would be to make the sounds appear to be coming from different locations in auditory space.

Tactual Displays

Tactual displays can make use of both cutaneous and kinesthetic information and include tactile maps and simple vibration. Past experience shows that direct, unprocessed transfer of video images to large two-dimensional tactile array is not suitable for mobility. Furthermore, from a technical standpoint, it should be noted that large tactile arrays have been, to date, unreliable. However, new methods of coding or preprocessing spatial information before it is presented to such displays, and new display technology that makes two-dimensional arrays more technically realistic, should not be ruled out.

More modest use of tactile displays, such as in one-dimensional arrays, has proven technically feasible and capable of transferring considerable information, especially in the field of auditory substitution. This type of display should therefore be explored, along with single-point stimulation or variable-frequency vibration. Dynamic computer-controlled tactual maps, should a feasible technology emerge for their implementation, could be useful in orientation training and research.

RECOMMENDATION: We recommend that research be continued on new methods of tactual display, emphasizing preprocessing and ease of interpretation of displayed information. Research and development efforts should be initiated to investigate the feasibility of new tactile display technology with the goal of fabricating dynamic computer-controlled tactual maps to be used in mobility training and research.

Visual Displays

Even the most rudimentary residual visual function may be used for presentation of environmental information, although not necessarily in a conventional way. Those with visual function at the level of "light perception" probably have significant temporal luminance modulation bandwidth that could be exploited for display of environmental information. If an individual has trichromatic light perception, the possibilities are significantly increased by providing color cues.

RECOMMENDATION: Research should be conducted on novel ways of presenting information obtained from any visual information acquisition device to the severely impaired eye. Attempts should be made to permit the use of head movements in order to avoid the encumbrances of a hand-held device.

Exploration should be made of the development of opto-electronic distance magnifiers and locomotion aids, given the existence of commercially available miniature video cameras and heads-up display technology being developed for pilots, to determine the usefulness of these new technologies to enhance the mobility of partially sighted people. These systems could help solve the problems of optical leverage with electronic damping of image translation and perhaps provide image processing tailored to an individual's impairment.

Combination or Multimodal Displays

Combinations of auditory and tactile and visual display technology may enable greater information display capabilities. A one-dimensional tactile display, for example, could be used to provide distance or direction information for nearby objects whose description is given auditorially (e.g. with a one-word verbal descriptor) after the manner suggested by Collins and Deering (1984).

RECOMMENDATION: Combinations of display technologies should be explored, in particular combinations of visual displays with auditory or tactile input for partially sighted people and combinations of auditory and tactile input for blind people.

Technology for Information Processing

Contributions are anticipated from both signal-processing techniques and from selected subfields of artificial intelligence. Promising areas include:

- (1) Signal processing--e.g. image processing, including noise filtering, edge enhancement, and contrast enhancement and
- (2) Artificial intelligence--e.g. computer vision, including image analysis for object identification and contour following for map correlation; natural language, including voice input, synthesized speech output, and dialogue management; and inference mechanisms, including expert systems and script-based situation analysis.

A final comment on the dynamics of technological development in our society is in order, for technology development has implications for research in the area of mobility for visually impaired people. Technology advance has sometimes been defined as a solution in search of a problem, and it is often cited as a primary cause whenever a technological device is produced that does not succeed in the marketplace. It is important to remember that technology advance is probably inevitable: it can be controlled but not eliminated. The only way to reduce its negative impact is through better theoretical and practical understandings of the problems in advance. And that requires that basic research on several facets of orientation and mobility be carried out.

RECOMMENDATION: Research should be carried out to study the feasibility of incorporating contemporary and future electronic processing capabilities into mobility aids for the visually impaired to make devices "smarter" and easier to use.

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GLOSSARY

Cognitive Mapping. The ability to understand the layout of the larger spatial environment in which purposeful activity is undertaken.

Disability. Limitations in carrying out tasks, involving such factors as motivation, training, and resources needed to accomplish tasks.

Electronic Travel Aid (ETA). Also electronic mobility aid. Any one of several electronic devices on the market designed to detect obstacles or to orient the blind or visually-impaired traveler. Examples include the Russell Pathsounder, the Laser Cane, the SONA aid system. A type of sensory aid.

Handicap. Limitations in performing social roles or socially structured sets of tasks.

Impairment. The lasting consequences of pathology, affecting parts of the organism. Loss of vision or low vision arising from retinal destruction or deformities of the eye or through neurological damage.

Legal Blindness. An administrative definition used by some federal, state and private programs. Defined as 20/200 acuity or worse in the better eye with correction or a visual field of 20 degrees diameter or less.

Low Vision. Impaired vision which even after optical correction is severe enough to affect one's functioning visually. Visual acuity of 20/70 or less in the better eye is one commonly used objective measure. (Excludes people who are totally blind.)

Mobility. Generally, movement from place to place. Used here to mean movement undertaken to reach a destination, implicitly involving elements of orientation and obstacle avoidance.

Mobility Specialist. An individual with training in the mobility problems of blind and visually-impaired persons, usually holding a B.A. or M.A. degree, whose primary job it is to assist the visually-impaired

person in learning how to travel efficiently, effectively, and safely, including training in the use of mobility aids. Referred to elsewhere as orientators, orientation and mobility instructors, and peripatologists.

Orientation. Collection and organization of information concerning the environment and one's relationship to it. For the visually-impaired person this involves the process of utilizing the remaining senses in establishing one's position and relationship to all other significant objects in one's environment.

Pathology. A medically determined disease or disorder (including trauma, structural abnormality, etc.).

Preprocessing. The processing of data by a machine prior to its presentation to the user in a coded form.

Transducers. Electronic component that translates physical energy of one type into energy of another type. Usually used in conjunction with a sensor.

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